# Nuclear Power

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

...in progress under
...ons of extreme cleanliness
... top of the stainless
...essel containing the fast
...r at Dounreay.
...essel is placed centrally
...oncrete "vault" containing
...ry liquid metal circuits
...eat-exchangers. The
...is in turn contained in the
... steel sphere which is
...ell-known exterior aspect
...ain's full-scale fast
...er reactor.

Taking the heat from the Nuclear Reactor

A boiler-maker takes heat from a source, whether it be coal, oil, gas or waste by-product, and produces steam under controlled conditions. For well over a century John Thompson have done this. Now they also do it with nuclear reactors. For the U.K. Atomic Energy Authority's full-scale experimental fast-breeder reactor at Dounreay they have produced the complex stainless steel reactor vessel, the primary liquid metal circuits and heat-exchangers and the secondary boiler plant complete with instrumentation and water treatment plant. At Berkeley, where one of Britain's first commercial gas-cooled nuclear power stations is being built by the AEI—John Thompson Nuclear Energy Company Ltd., they are building the 1,000 ton reactor vessels, gas-ducting, heat exchangers and fuel loading equipment.

JOHN THOMPSON GROUP

JOHN THOMPSON LIMITED · WOLVERHAMPTON



ROWSE MUIR PUBLICATION

JUNE 1958 3/6

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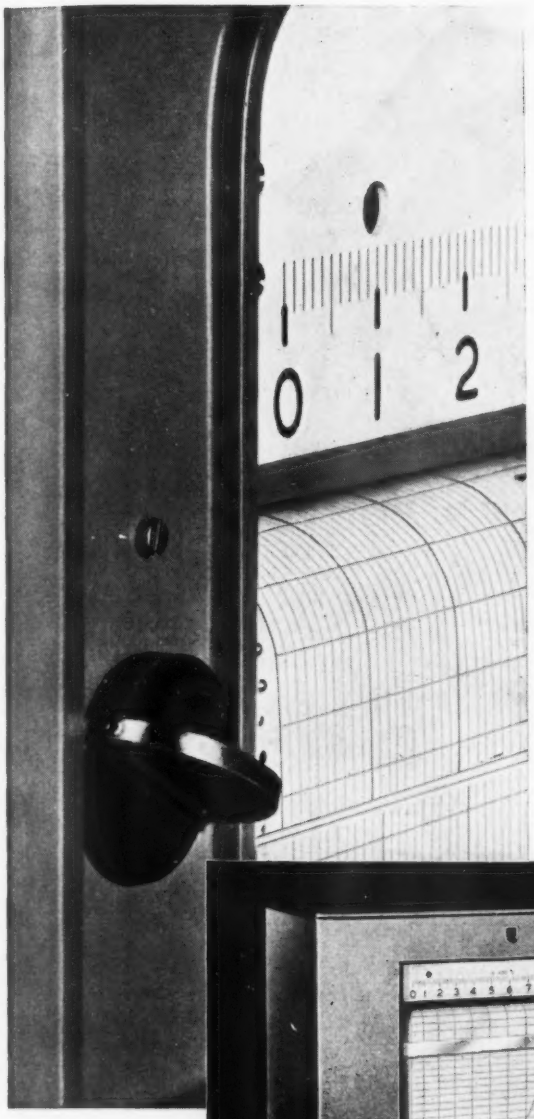


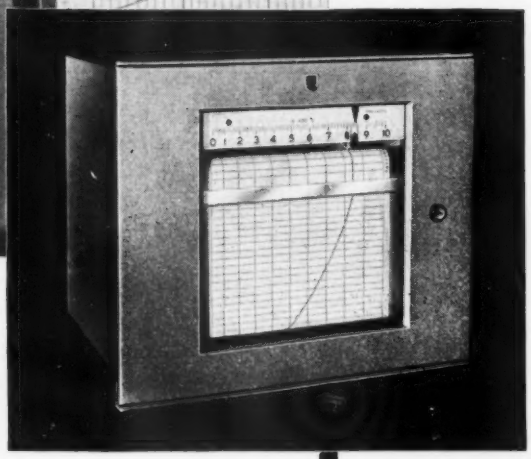


To position the chart with hair-line accuracy, it is only necessary to disconnect the chart-drive by means of a simple lever, and to adjust the position of the paper with the knob shown above. Returning the release lever re-engages the drive, which is through a four-speed gear box.

# Start right with **PHILIPS** potentiometric recorders

Philips potentiometric recorders are *trusted* instruments. Whether applied to experimental and behaviour studies, for building into equipment or to industrial process control they have earned the confidence of the most experienced users.

If you are concerned with the measurement, recording or control of any variable such as temperature, conductivity, strain, vibration, pressure, radiation or any phenomenon to which a transducer or other primary measuring element is responsive, get to know about potentiometric recorders by Philips.

Operating on the servo-operated null-balance principle, Philips potentiometric recorders are available as single-channel instruments, in double-channel form and as multiple-channel recorders up to twelve positions. From a comprehensive range there is an instrument to meet every need. Write now for fully descriptive literature.

*Sole Distributors in U.K.*

**RESEARCH & CONTROL INSTRUMENTS LTD**

**Instrument House · 207 Kings Cross Road · London W.C.1**

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PHILIPS

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(RCIL0350)

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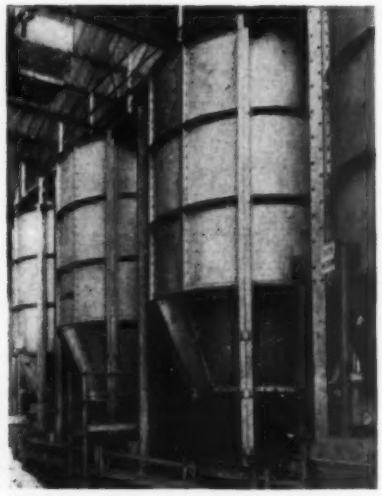
# *call in the specialists*

**Specialists for 30 years in the manufacture of mechanical materials handling aids for every industry. Paterson Hughes produce the finest complete schemes and equipment to suit any application. A satisfactory materials handling scheme, designed to fulfil specific requirements effects considerable economies of labour and space. For the major step to higher production, consult**



**PATERSON HUGHES**
ENGINEERING COMPANY LIMITED

## *MECHANICAL HANDLING ENGINEERS AND CRANE MAKERS*

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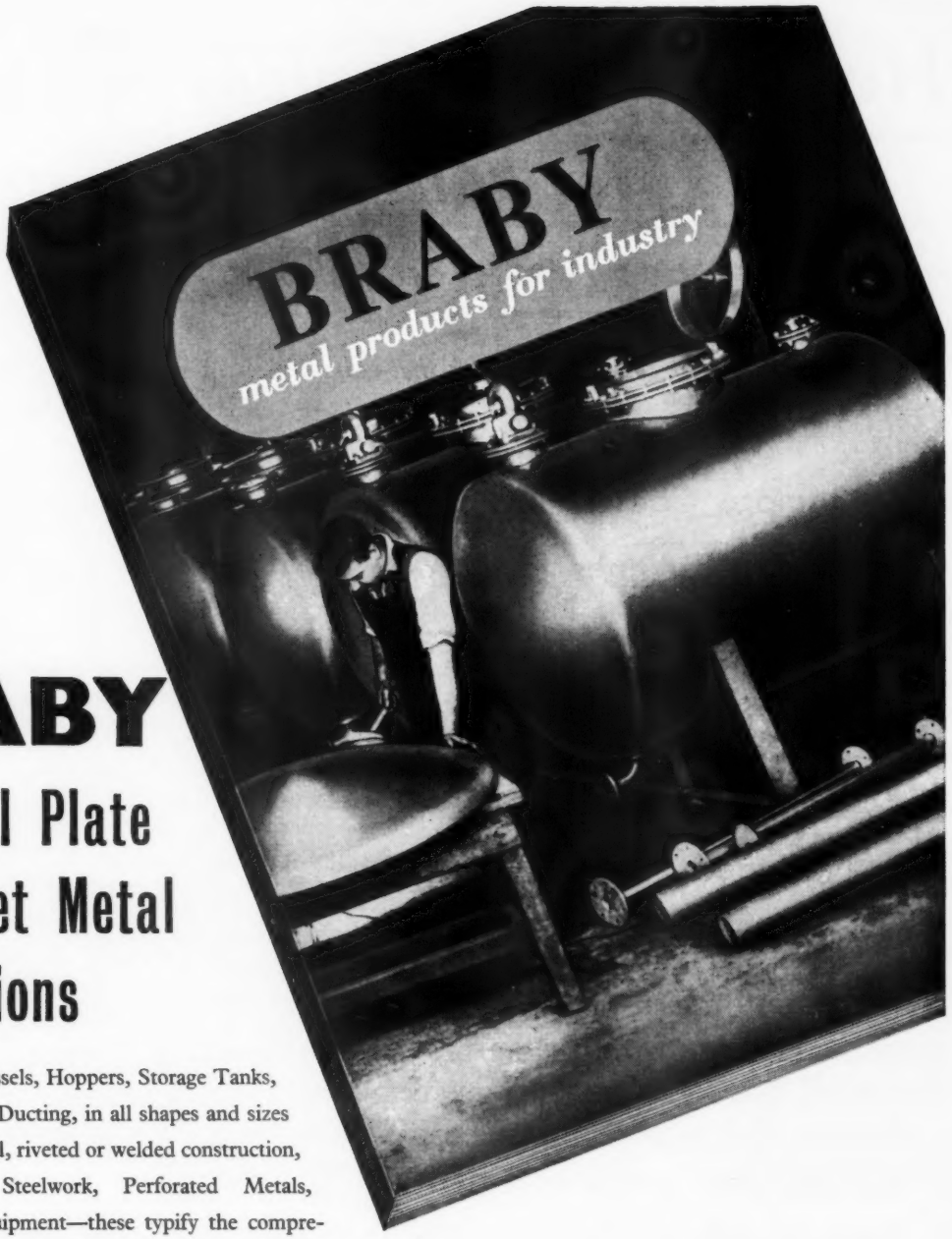
P 4334




# BRABY

## for Metal Plate and Sheet Metal Fabrications

Pressure Vessels, Hoppers, Storage Tanks, Containers, Ducting, in all shapes and sizes and in bolted, riveted or welded construction, Structural Steelwork, Perforated Metals, Storage Equipment—these typify the comprehensive nature of the Metal Plate and Sheet Metal Work that BRABY supplies to British Industry.

All are featured in a newly-published brochure, 'BRABY Metal Products for Industry,' which also includes some useful trade memoranda. Copies are available on request.

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Queen's Buildings, 10 Royal Avenue, **Belfast.** TELEPHONE: Belfast 26509
Palace Street, **Plymouth.** TELEPHONE: 62261

*AP 62*

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# *Have you a problem in remote handling?*

## *If so, we can help you!*

*We have already been entrusted with the manufacture of the following equipment :-*

Remote Control Machines for Element Handling

★ **REMOTELY CONTROLLED LATHES**—
*For producing test pieces from enriched uranium elements.*

★ **X-RAY MACHINES & CASSETTE MECHANISMS**—
*For X-raying irradiated fuel elements by remote means.*

★ **END REMOVAL AND STRIPPING MACHINES**—
*For removal of the nose and tail units and stripping of the stainless steel Sheaths from the elements.*

★ **SEPARATION MACHINES**—
*For separating the fuel elements from the breeder elements.*

★ **GENERAL-PURPOSE CUTTING MACHINES**—
*For removal, by slitting, of the stainless steel Sheaths from the elements and for slicing up of uranium elements.*

★ **ELEMENT RECANNING MACHINES AND OPERATING GEAR**—
*For recanning used uranium fuel for transport purposes.*

Machined Components and Assemblies

★ **CRUSHING PRESSES**—
*50-ton presses for crushing uranium elements for subsequent test purposes.*

★ **ZINC BROMIDE VIEWING WINDOWS**—
*For irradiated fuel element laboratories.*

★ **SERVICE SLEEVES**—
*For manipulators, electrical and hydraulic controls.*

★ **COOLANT CHANNEL GAG ASSEMBLIES**

Having the most comprehensive engineering plant in the South, we can offer complete design and manufacturing facilities for all types of remote control equipment and precision machining of components and assemblies.

*We thus take responsibility from inception, through design, manufacture and installation.*

**J. EVANS & SON (PORTSMOUTH) LTD**
**MARCYN WORKS - GOLDSMITH AVENUE**
**PORTSMOUTH**

**Tel.: 32233-6 (4 lines)** **Grams: "Marcyn, Portsmouth"**

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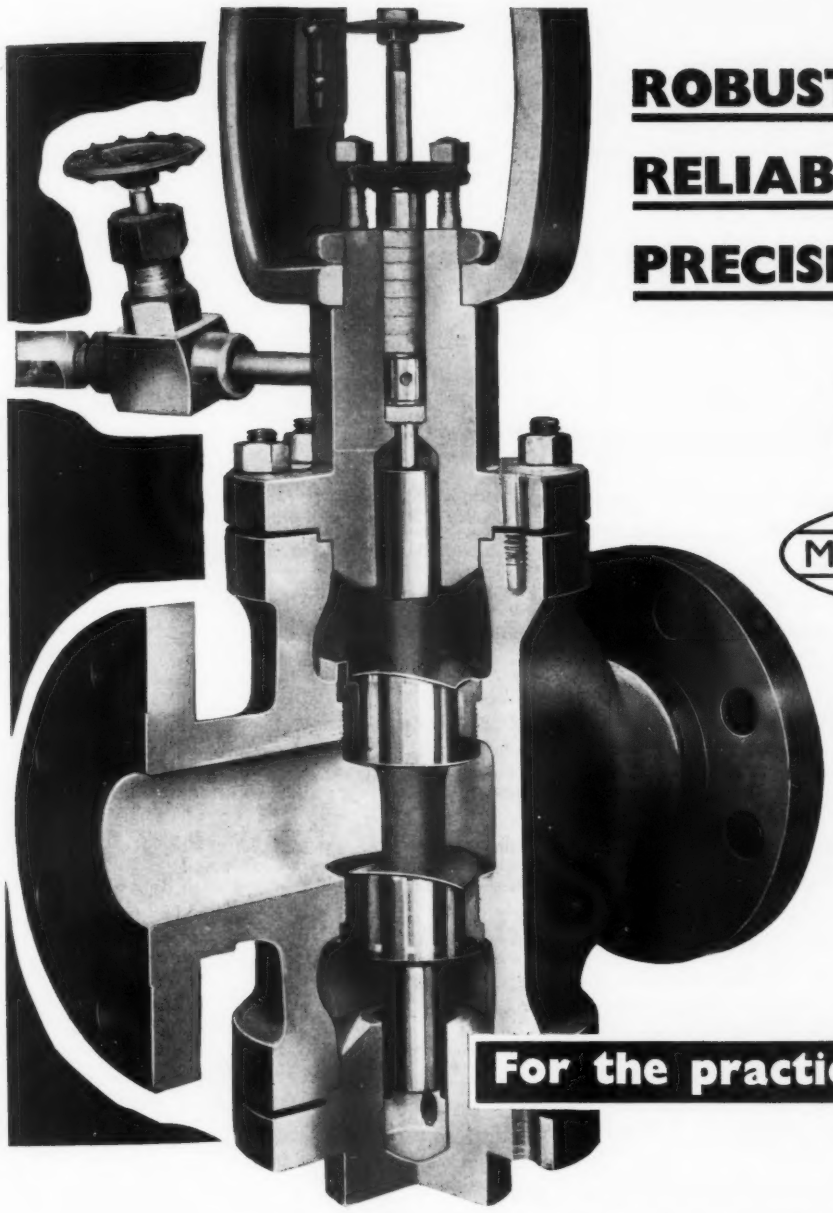

**ROBUST . . .**

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**PRECISION MADE**

*The*

MASONEILAN

*Control Valve*

**For the practical engineer**

Consider these features — centrally top and bottom guided plug — piloted seat rings — characterised solid skirted plugs — hardened guide bushes — high capacity 'D' shaped body — bolted stuffing box — body invertible for reversing valve action — yoke bowed for gland accessibility.

Complete details on application

CROSBY

**THE CROSBY VALVE AND ENGINEERING CO LTD**

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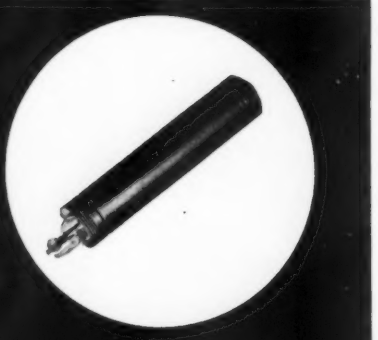
20th CENTURY

# TUBES FOR REACTOR INSTRUMENTATION

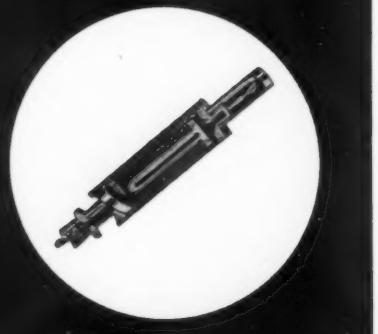
## SLOW & FAST NEUTRON DETECTORS

For detecting and measuring thermal neutron flux $BF_3$ proportional counters are available in which $BF_3$ gas enriched in B-10 is used at a variety of pressures to cover a wide sensitivity range.
Fast neutron health hazard can be directly assessed by the FN series of proportional counters which are designed to simulate tissue response to fast neutrons.



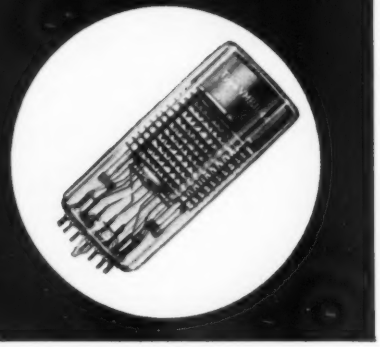
## FISSION CHAMBERS

The fission chamber type B165 operating as a pulse ion chamber, is currently employed as a detector of neutrons in the pulse counting equipment of reactor instrumentation.
Internal coatings of enriched or depleted fissile material are available in the B165 and in smaller chambers which have been designed for use as probes in neutron flux investigations.



## PHOTO MULTIPLIERS

A range of photo-multiplier tubes is available for scintillation counting, energy resolution and applications where linear high current output is necessary.
These tubes employ from 6 to 18 stages of multiplication and the smallest has an overall diameter of $\frac{3}{4}$".



20th CENTURY ELECTRONICS LIMITED

**CENTRONICS WORKS · KING HENRY'S DRIVE**

**NEW ADDINGTON · CROYDON · SURREY** · *Lodge Hill 2121*

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# The 'AVO' D.C. AMPLIFIER

## TYPE 1388B

### *A Portable Micromicro-ammeter*

THIS is a highly stable D.C. Amplifier which has been primarily designed to measure the minute currents produced in ionisation chambers, but it has various other applications in medicine, industry and experimental work in connection with reactor instrumentation.

The majority of organisations using radioactive materials have, in the past, set up apparatus for checking the activity of their specimens, the equipment usually comprising a geiger counter, scintillation counter or ionisation chamber, all of which require to be calibrated from time to time with standard radioactive sources. Some of these materials have a limited useful life due to the rapid decay of their activity, and thus the preparation or acquisition of fresh standards has been continuously necessitated. The demand for such standards has, however, now been considerably reduced, and the calibration procedure greatly simplified by the introduction of a standard form of equipment for secondary standardisation, the National Physical Laboratory Advisory Committee on Radioactive Standards, and the Atomic Energy Research Establishment, Harwell, having jointly arranged for the commercial production of ionisation chambers to measure beta and gamma sources in the range of 1 microcurie to a few millicuries.

Tests indicate that the calibration factors for standard gamma sources will be the same within ± 1%, for all chambers which conform to the specified design, the limits for beta sources being approx. ± 3%, ionisation currents being measured on the "AVO" Portable D.C. Amplifier which has been designed by and produced in conjunction with the Atomic Energy Research Establishment, Harwell. The instrument complies with the general requirements of the Inter-Services Specification K114E (for the climatic and durability testing of service equipment) as laid down by the Radio Components Standardisation Committee of the U.K. Ministry of Supply.

**DESCRIPTION:**
The "Avo" D.C. Amplifier, type 1388B, is a mains operated transportable D.C. Amplifier for the measurement of minute currents. The current to be measured develops a voltage across a high value resistor. This voltage is amplified and fed to an indicating meter. 100 per cent. negative feedback is employed so that readings are independent of the amplifier gain. A control is fitted to vary the time constant of the input stage.

**RANGES:**
Seven input ranges are provided. By selection, full-scale sensitivity of 3V or 10V enables measurements to be made from a first indication of $10^{-14}$ Amps. to a maximum of 1μA.

**ACCURACY:**
The instrument is set up during manufacture to a current accuracy of ±3 per cent. at full-scale deflection.

**RECORDER OPERATION:**
A 100mV output is provided for recorder operation. Output impedance of 100Ω provided via a cathode follower stage.

**STABILITY:**
A change in mains voltage of ±10 per cent. produces a zero error of less than 10mV. The long term stability is less than 25mV variation over several weeks running.

**ACCESS TO FEEDBACK LINE:**
Provision has been made for access to the feedback line to enable long time constants to be obtained such as are required for slow neutron count.

**100 VOLTS OUTPUT:**
A potential of 100V is provided for polarising the ionisation chamber.

**MAINS INPUT:**
105-120 volts A.C. and 180-250 volts A.C., 40-60 c/s. These are selected by means of a voltage selector on the front panel.

**CONSTRUCTION:**
The instrument is built on a light alloy framework which, together with the front panel, is contained in a strong aluminium case fitted with a cover and a carrying handle. The electrometer valve and its associated high impedance circuitry are contained in a sealed desiccated unit which is fitted to the inside of the front panel.

**DIMENSIONS:** 15 × 11 × 7¾ inches, 38.1 × 27.9 × 19.7 mm.

**WEIGHT:** 20 lbs., 9.07 kgs. approx.

AVO LTD
AVOCET HOUSE · 92-96 VAUXHALL BRIDGE ROAD · LONDON · S.W.I. Telephone: VICtoria 3404 (7 lines)
Manufacturers of:—ELECTRICAL, ELECTRONIC & NUCLEONIC INSTRUMENTS · DOUGLAS & MACADIE COIL WINDING MACHINES
DCA. 1.

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# CAPOSITE

single layer insulation

## Saves a layer— retains higher insulating qualities

CAPOSITE is a 'one-layer' form of insulation. Used either as block or preformed section, there is no need to apply any type of heat resisting material before the main insulation. Yet National Physical Laboratory tests show that there is no increase of heat loss when CAPOSITE is applied direct. In fact, thermal efficiency has been rated as high as 98%, and even contact up to 1000°F. shows no tendency to shrinkage which would result in heat loss. Being made from the uniquely long-fibred South African asbestos known as Amosite, CAPOSITE is clean to handle, has a low breakage loss in transportation or storage, and its inherent strength enables it to be handled efficiently in large size blocks and pipe section diameters and lengths.

CAPE

**CAPOSITE**

**Amosite Asbestos Blocks and Pipe Sections**

*Write for full technical details to:—*
**THE CAPE ASBESTOS COMPANY LTD.** 114 & 116 Park Street, London W.1. Tel: GROsvenor 6022
and at: GLASGOW: Eagle Buildings, 217 Bothwell Street, Glasgow, C.2. Tel: CENtral 2175
MANCHESTER: Floor D, National Buildings, St. Mary's Parsonage, Manchester 3. Tel: Deansgate 6016-7-8
BIRMINGHAM: 11 Waterloo Street, Birmingham 2. Tel: Midland 6565-6-7
NEWCASTLE: 19 & 20, Exchange Buildings, Newcastle. Tel: Newcastle 20488

TA236

# of the Atom

To nuclear power generation Simon-Carves bring immense experience of major plant construction and civil engineering for the fuel, electricity and heavy chemical industries, including the building of orthodox steam power stations for more than thirty years.

In the building of nuclear power stations Simon-Carves assume responsibility for all civil engineering and reinforced concrete design and construction, including nuclear reactor structures and biological shielding, and for complete heat-exchange steam-generating plant and water treatment systems.

Simon-Carves are conducting continuous research, both in their own laboratories at Cheadle Heath and jointly with The General Electric Company at Erith, on the improvement of steam conditions resulting from improved reactor outputs, on the use of pre-stressed concrete in reactor structures and elsewhere, and on the safe disposal of radio-active waste.

This work is playing an important part in the development of future advanced designs and in the reduction of cost per kilowatt.

## *Simon-Carves Ltd*

SIMON ENGINEERING GROUP

*NUCLEAR POWER DIVISION / Cheadle Heath, Stockport*

IN ASSOCIATION WITH THE GENERAL ELECTRIC CO. LTD
THE MOTHERWELL BRIDGE & ENGINEERING CO. LTD · JOHN MOWLEM & CO. LTD

SC177(A)/PS

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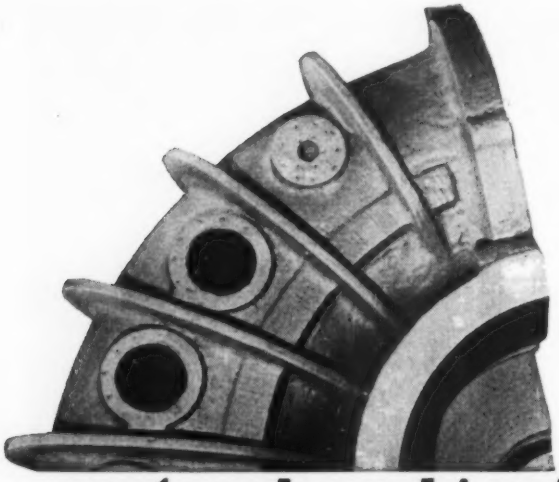


*Half gas circulator casing cast in steel and machined for C. A. Parsons & Co. Ltd. for Nuclear Power Station, Calder Hall. Weight as cast 35 tons. Sectional thickness max 7" min 1½". Reproduced by permission of C. A. Parsons & Co. Ltd.*

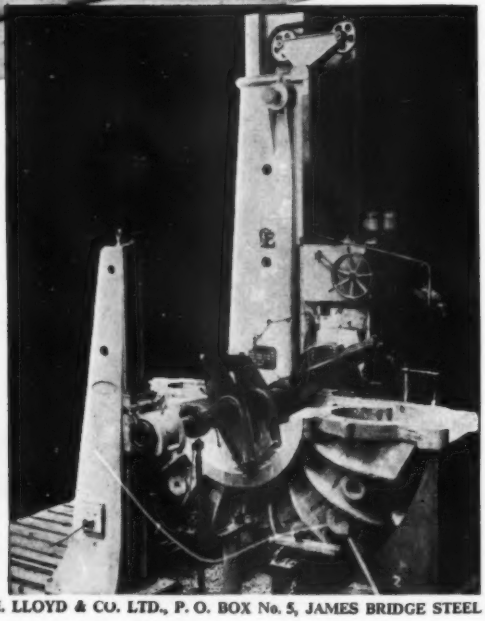
# cast and machined for an important part

Steel castings are performing a number of important functions in the production of Nuclear Power, not least being the gas circulator casings cast for C. A. Parsons & Co. Ltd. reactors.

They form an integral part of the atomic pile, circulating as they do the carbon dioxide coolant through the reactor. Their dimensional accuracy and tolerances must be of a far higher standard than is usual in normal engineering practice.

The exacting nature of the service conditions also demands the most meticulous inspection, including radiographic examination and magnetic crack detection.

It is because of this need for flawless castings that Lloyds, with their unsurpassed facilities for scrupulous control at every stage of production and inspection, are called upon to cast and machine these vital components.



*TYPICAL LLOYDS STEEL SPECIFICATION*
*used for general engineering requirements. Grade M. B.S 592, Grade B 0.30% carbon, Annealed, Yield Stress 16/19 t.s.i., Ult. Stress 32/37 t.s.i.; Elongation 30/20%; R.O.A. 40/25*

# LLOYDS

***Britain's best equipped steel Foundry***

**F. H. LLOYD & CO. LTD., P. O. BOX No. 5, JAMES BRIDGE STEEL WORKS, WEDNESBURY, STAFFS. TELEPHONE JAMES BRIDGE 2401**

A Print for Industry Ltd. advertisement

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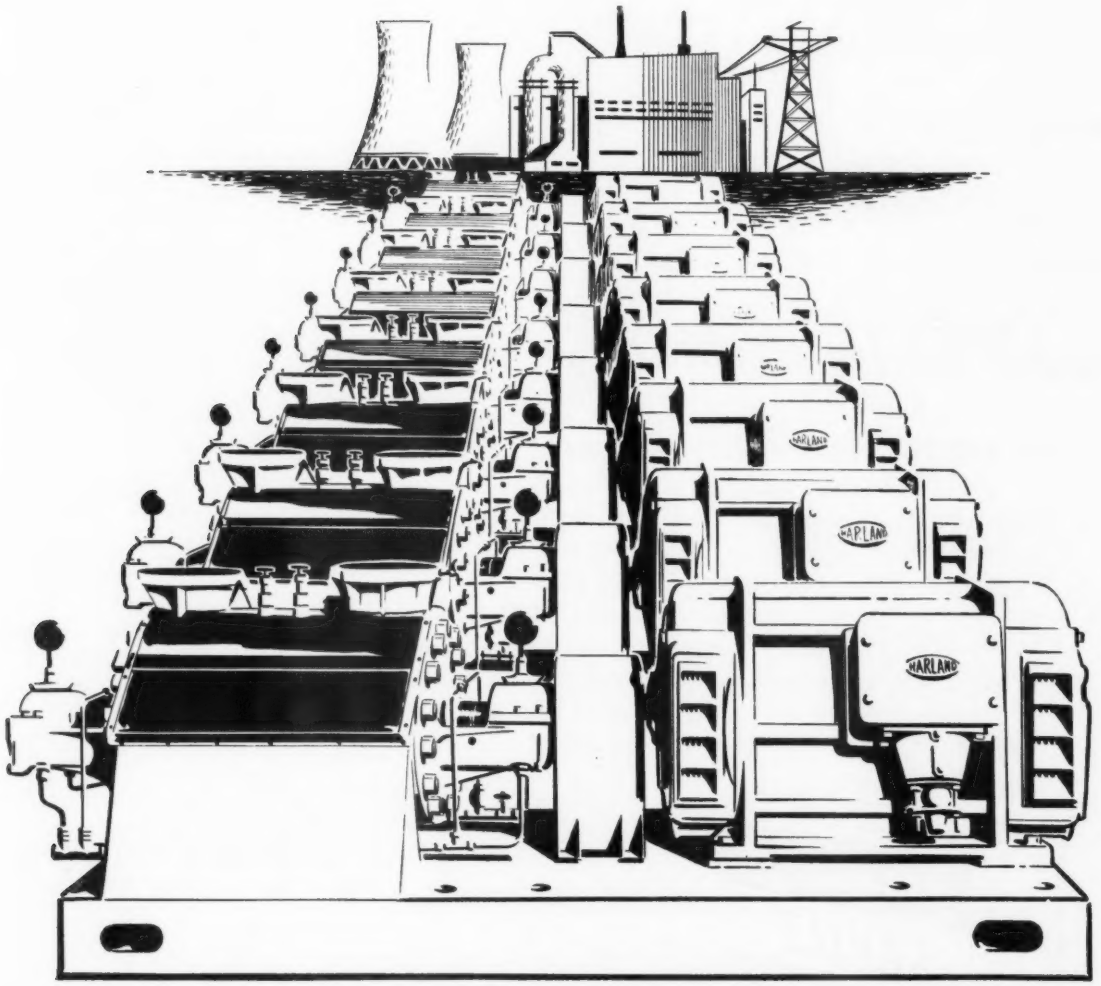
# HARLAND

## BOILER FEED PUMPS

### at

## Bradwell

On behalf of the Nuclear Power Plant Company, Messrs. C. A. Parsons have placed with Harland the contract for 10 groups of boiler feed pumps complete with motors for this major nuclear power station to be commissioned by the Central Electricity Authority within their first Nuclear Power programme.




**THE HARLAND ENGINEERING CO LTD ALLOA SCOTLAND**

*LONDON & EXPORT SALES OFFICES: HARLAND HOUSE 20 PARK STREET W1*

BRANCHES IN BRISTOL GLASGOW LEEDS NEWCASTLE NOTTINGHAM TIMPERLEY (Cheshire) WOLVERHAMPTON & Overseas

III

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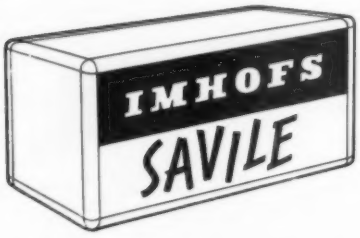
## *Can't find a standard case to meet the problem?*

# SAVILE TAILOR-MADES *provide the answer!*

***ANY SIZE! ANY QUANTITY! 14 DAYS DELIVERY!***

Strongly-built with the unique Imlok construction system and beautifully finished, these cases (racks or consoles) are made to your own specification and *supplied in any quantity*. Prices are competitive and generous discounts are available for large orders. That means for prototype work or batch productions you can still enjoy the economy of using standard designs, yet get a 'made-to-measure' job. Handles and all accessories to suit your requirements. Write now for full details and convenient order form.




***tailor-made cases***

**ALFRED IMHOF LIMITED** **Ashley Works Cowley Mill Road Uxbridge Middlesex Tel: UX5-5567**
*Export & London Showrooms: 112-116 New Oxford Street WC1 Tel: MUSeum 7878*

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# More than 80
# SUNVIC Mk.IIA STRIP CHART RECORDERS
# will be used at Berkeley...

... for monitoring:

***LINEAR POWER***

***BACKED-OFF LINEAR POWER***

***LOGARITHMIC POWER***

***LOW LOGARITHMIC POWER***

***LOW POWER COUNTER CHANNEL***

***FUEL ELEMENT CAN SURFACE TEMPERATURES***

***DUCT $CO_2$ TEMPERATURES***

***CHANNEL $CO_2$ TEMPERATURES***

***GRAPHITE TEMPERATURES***

***PRESSURE VESSEL AND DUCT TEMPERATURES***

***BIOLOGICAL SHIELD TEMPERATURES***

***FLUX DISTRIBUTION***

***CONTROL ROD POSITIONS***

***BURST CARTRIDGE ACTIVITY***

***SUMMATED GAS FLOW***

***WATER CONTENT OF $CO_2$***

***$CO_2$ CONTENT OF STEAM***

***PRESSURE VESSEL GAS PRESSURE***

The flexibility of this new recorder is such that all will be *standard* instruments with *standard* additional facilities. These include :-

* High impedance input
* High and low level alarms
* Retransmitting slidewire
* Range change switch as well as plug-in bobbins
* Automatic cold junction compensation

All models have a totally enclosed slidewire and continuous stabilisation of the slidewire supply voltage. For full technical information, please contact: SUNVIC CONTROLS LTD., P.O. Box 1, HARLOW, ESSEX. Tel. HARLOW 25271

SUNVIC
An A.E.I. Company

*Not only instruments but complete instrumentation*
for integrated monitoring, control and data handling of nuclear reactors and industrial processes.

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# SAVILE TAILOR-MADES *provide the answer!*

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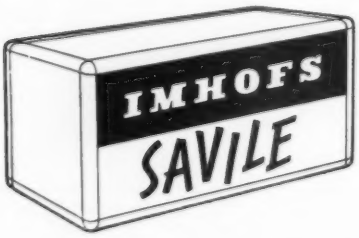


***tailor-made cases***

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LGB/SI

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***LOW POWER COUNTER CHANNEL***

***FUEL ELEMENT CAN SURFACE TEMPERATURES***

***DUCT $CO_2$ TEMPERATURES***

***CHANNEL $CO_2$ TEMPERATURES***

***GRAPHITE TEMPERATURES***

***PRESSURE VESSEL AND DUCT TEMPERATURES***

***BIOLOGICAL SHIELD TEMPERATURES***

***FLUX DISTRIBUTION***

***CONTROL ROD POSITIONS***

***BURST CARTRIDGE ACTIVITY***

***SUMMATED GAS FLOW***

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***$CO_2$ CONTENT OF STEAM***

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for integrated monitoring, control and data handling of nuclear reactors and industrial processes.

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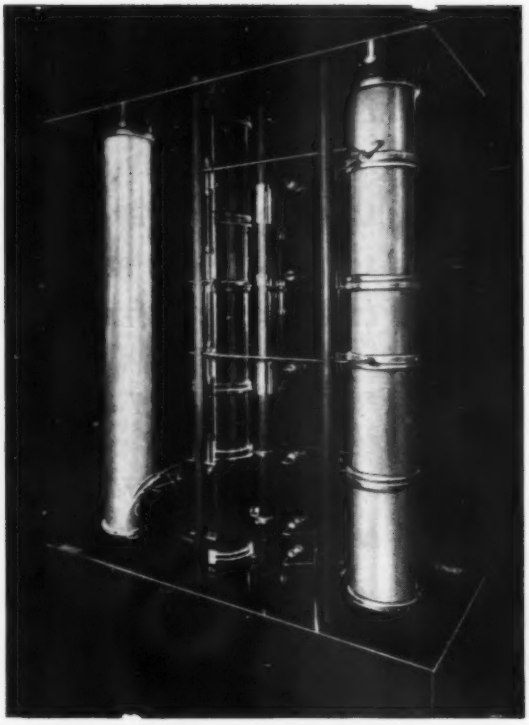
# high voltage ENGINEERING



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***It is complete with single sweep oscilloscope and measuring sphere gaps.***
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***A 350 kv. Generator complete with capacity divider — the ball gaps are remotely controlled from the desk.***

***The control desk, with charging unit incorporated, complete with single sweep oscilloscope and camera.***

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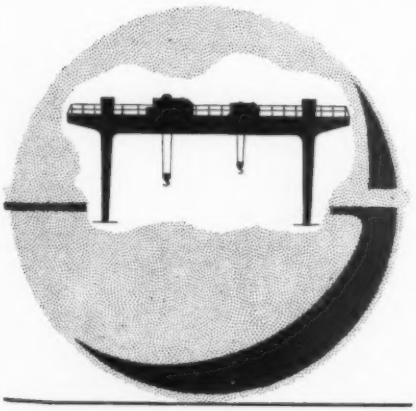
such as we have supplied for the following atomic power stations



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# VACUMELT

## VACUUM MELTED STEELS

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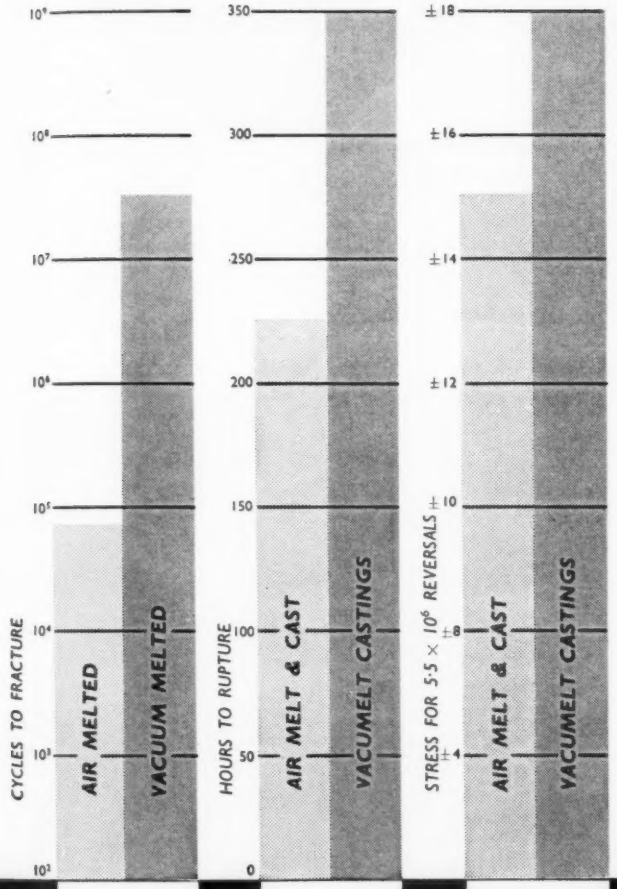


FATIGUE STRENGTH OF CARBON CHROMIUM BALL RACE STEEL

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FATIGUE STRENGTH OF CAST G34 (COBALT BASE ALLOY)

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Freedom from impurities means greater safety in highly stressed components.

***IMPROVED DUCTILITY***
Particularly in directions at 90° to grain flow.

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Vacumelt steels are readily available in most qualities. Ingots up to 2 tons can be produced and also blooms, billets, bars, forgings, sheet and strip. Among the many applications demanding the freedom from impurities offered by Vacumelt steels the following are obvious:—ball races and bearings, compressor blades and discs, turbine blades and discs, high grade polished sheet, certain high finish tools and dies, fine gauge steel wire.

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fabricated
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standards

MULTIRAIL fabricated steel handrail standards have proved to be as rigid as the solid forged type, with the advantages of four ferrules enabling vacant ferrules to be used in carrying power lines, air and gas pipes, etc.

"SAFETREAD" FLOORING IS

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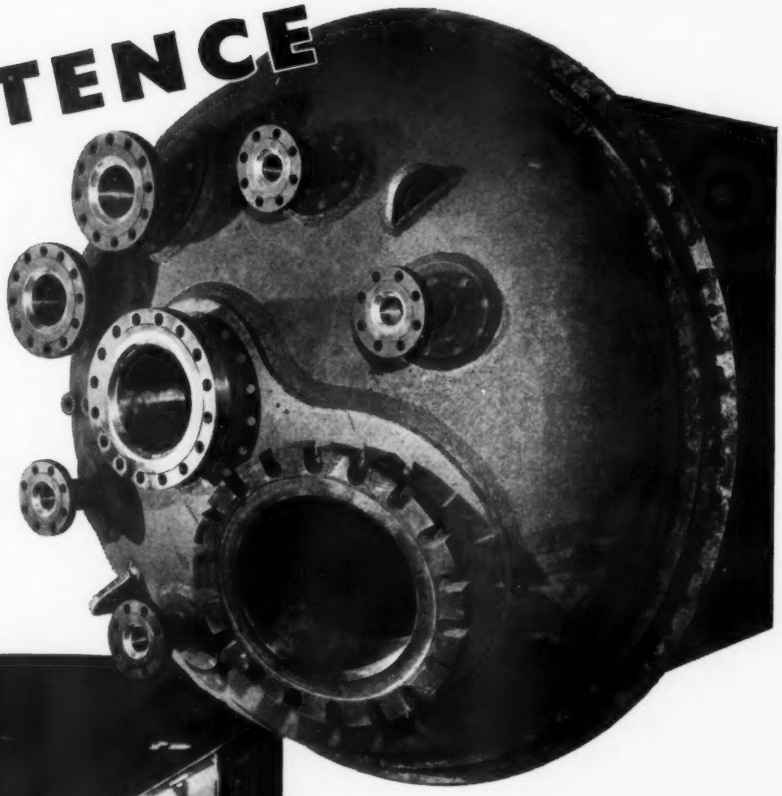
# COMPETENCE



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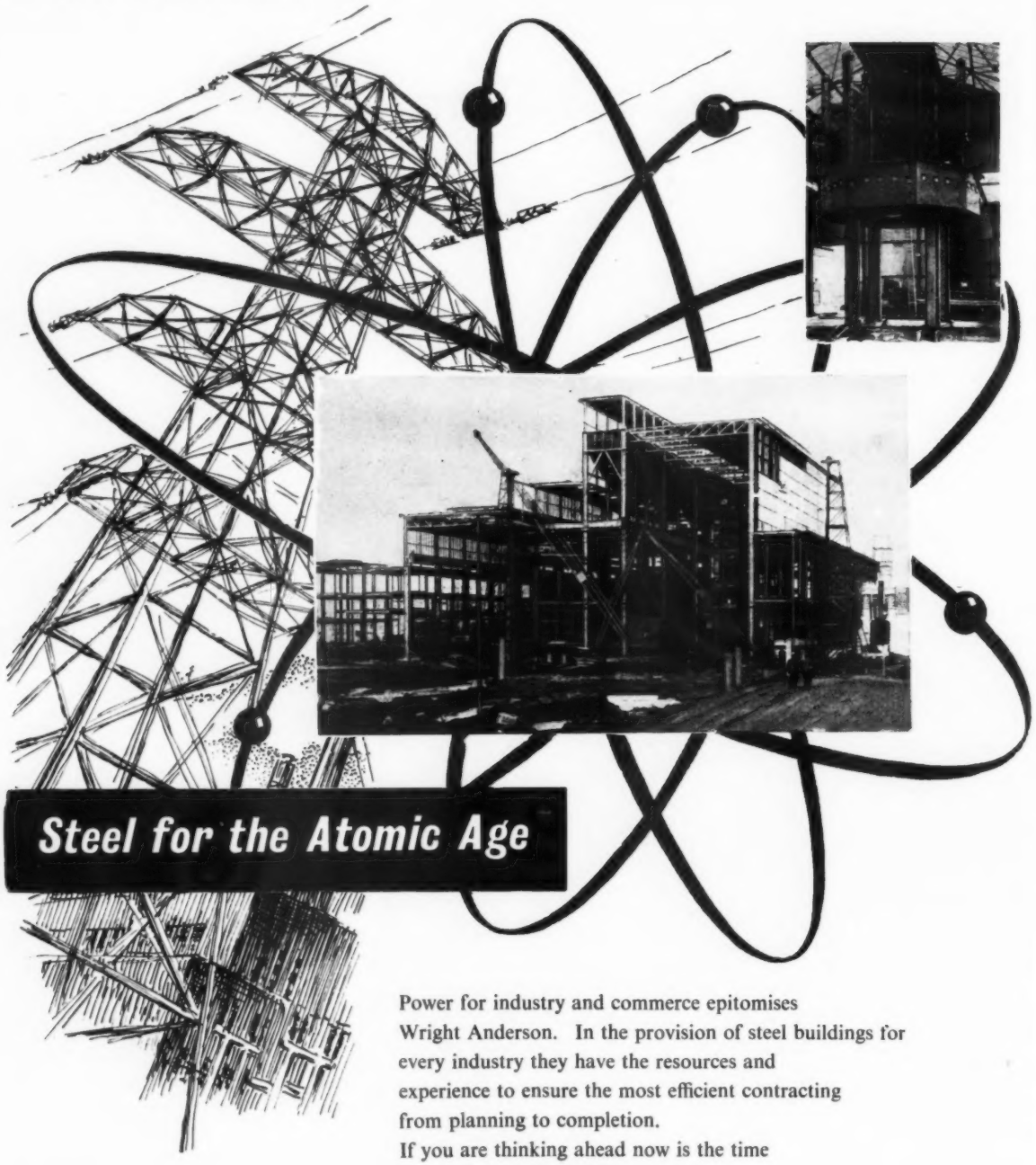

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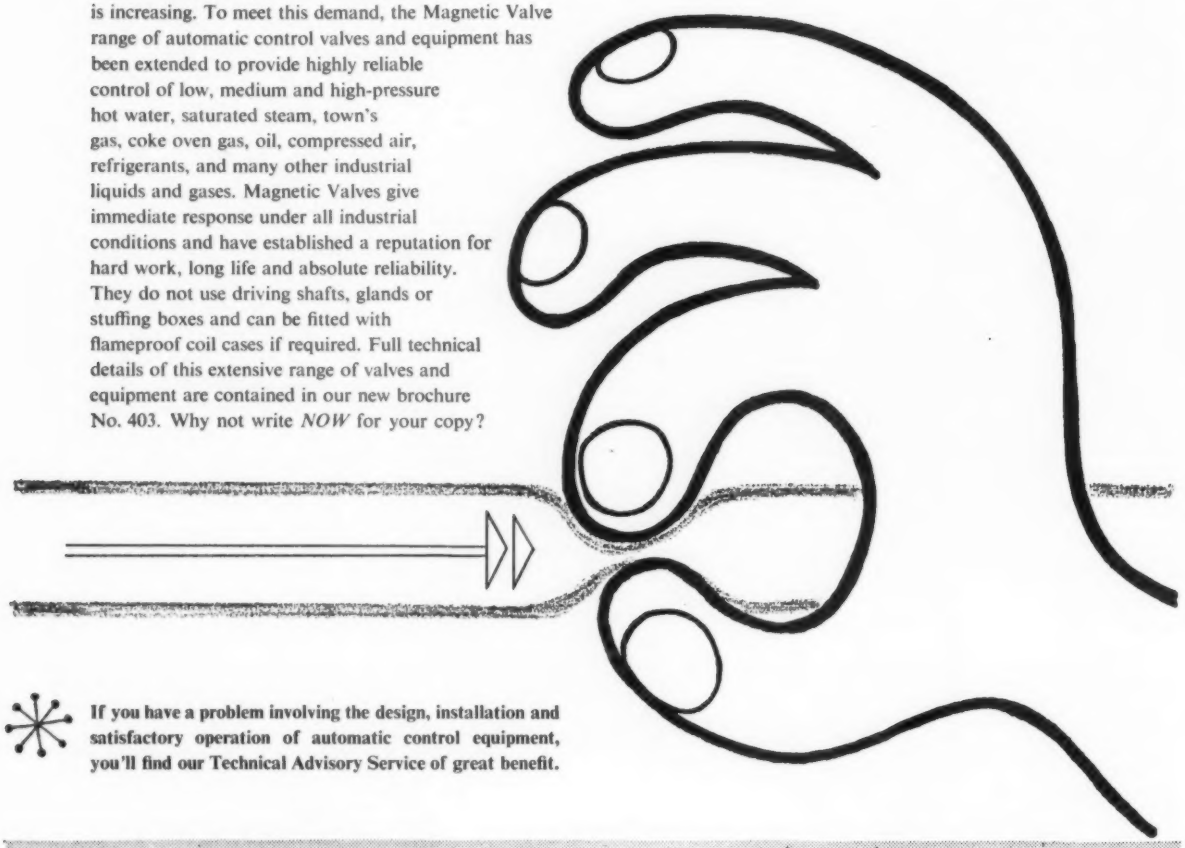

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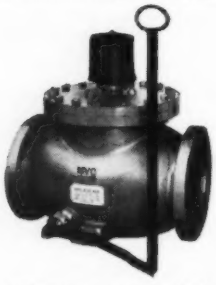

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MV3

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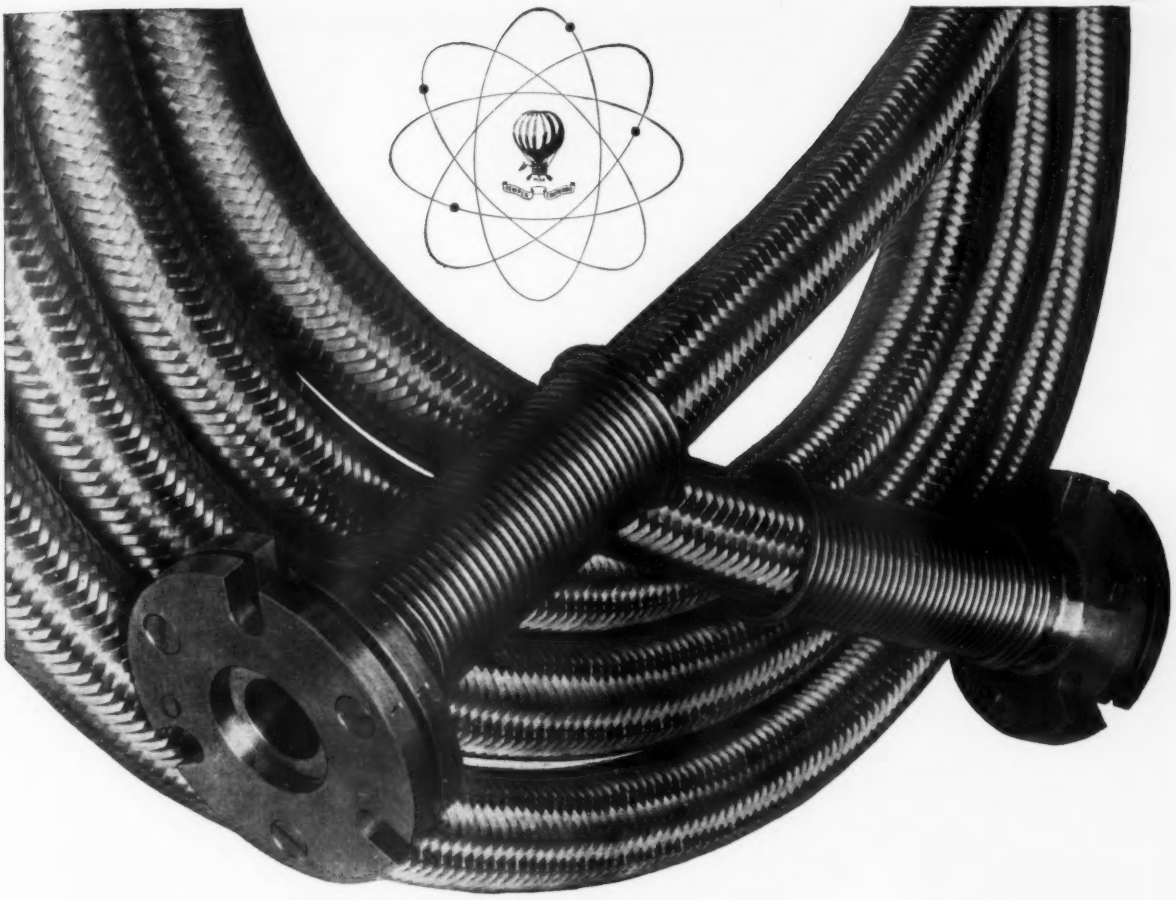

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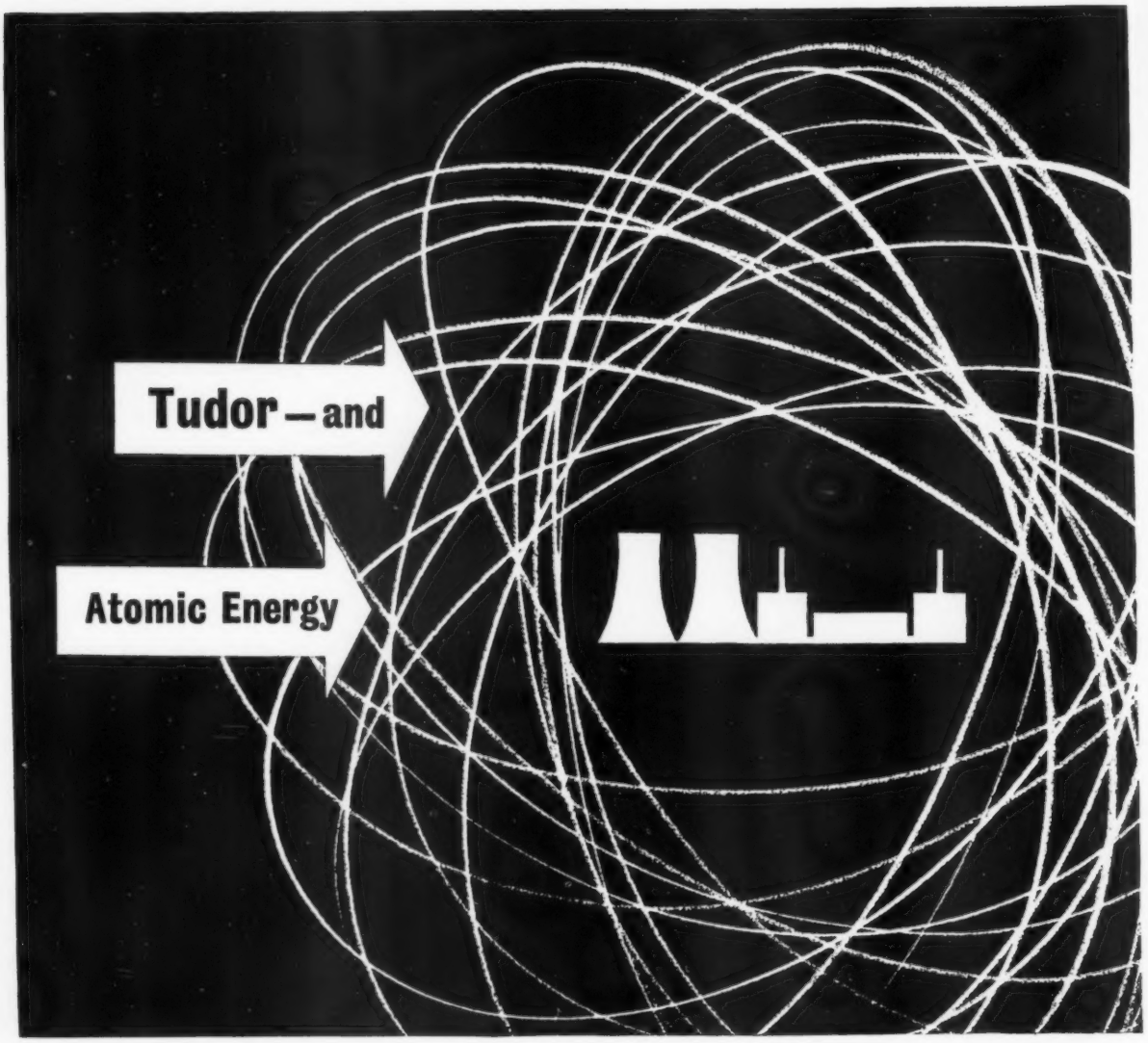


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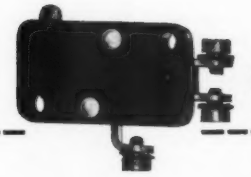

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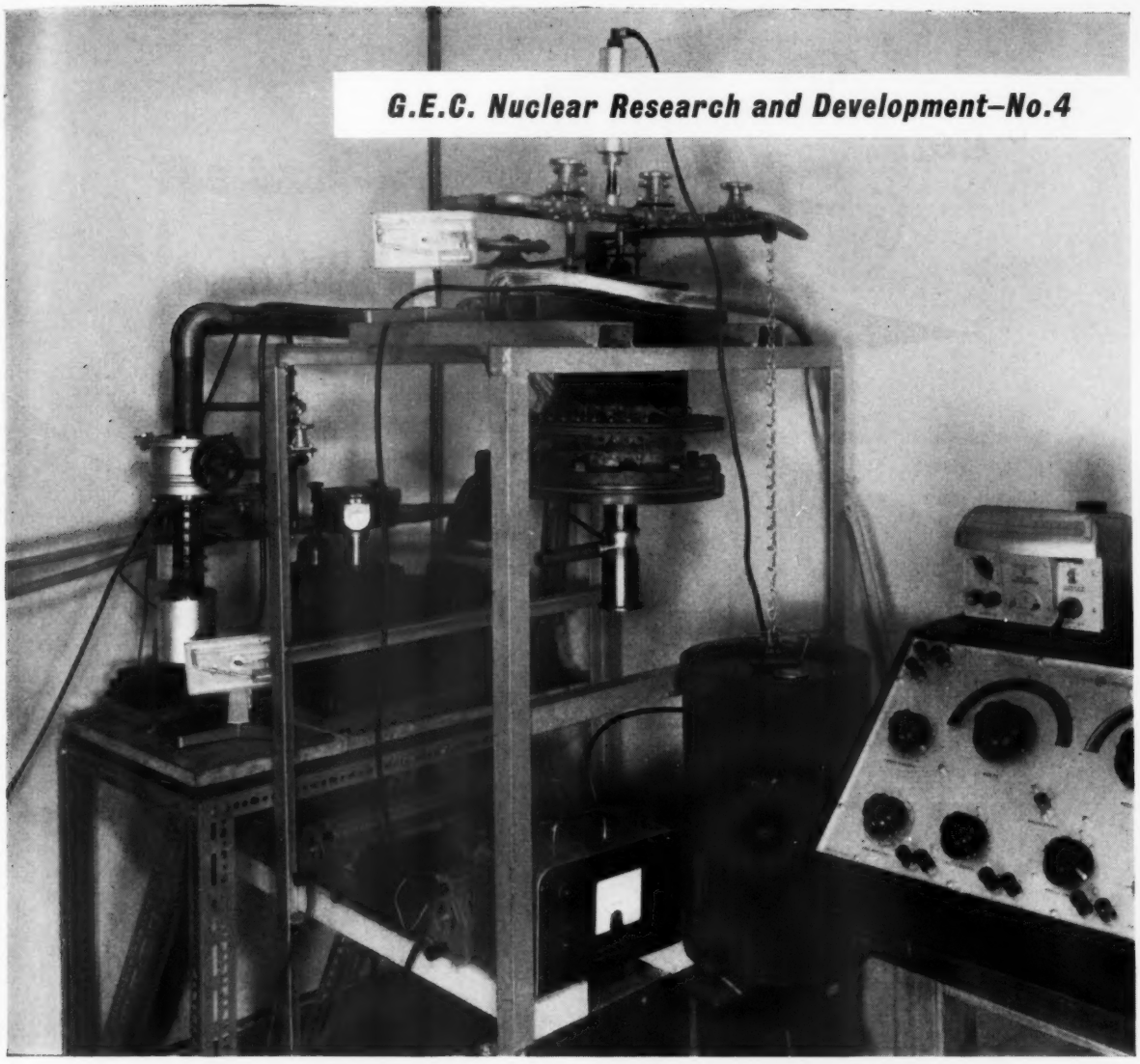

***G.E.C. Nuclear Research and Development–No.4***

# Uranium-to-can Heat Transfer

In a nuclear power reactor metallurgical considerations impose a limit on the temperatures that can be allowed in the uranium fuel rods. At the same time it is essential, for efficient heat transfer to the gas, that the can should be as hot as possible. It is thus necessary to determine the temperature drop that will occur between the centre and the surface of a fuel element.

The temperature drop between the centre and surface of the uranium is calculable by straightforward methods, but at the uranium/can interface a further drop takes place since the metal faces are not perfectly smooth. This can be determined only by experiment.

At the Erith laboratories of the G.E.C. the apparatus pictured above is used to measure the temperature drop as a function of surface temperature, for a variety of uranium surface finishes and with different gas fillings in the cans. One end of a cylindrical rod of canning material is heated, and heat flows along the cylinder, through a uranium test piece and into a second length of canning material, while thermocouples measure the temperature distribution along the heat path.

The results obtained facilitate the design of more efficient fuel elements and also make it possible to predict the temperatures that will prevail in the individual components under all possible conditions.

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*Atomic Energy Division*

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A239

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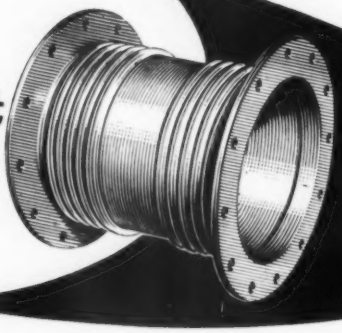
Let's get  together with . . .

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# The back-room boys look forward . . .

EVERY PART OF EVERY ASSEMBLY in a nuclear power station must be pre-tested to ensure 100% reliability. Metals must be specified and samples analysed. Parts subject to mechanical stresses must be tested at greater stresses to give a substantial margin of safety. Scale models must be made and tested so that the performance of major components can be forecast.

All this takes time. Laboratory research, by its nature, is always years ahead of site construction. At the Research and Development Laboratories of the United Kingdom Atomic Energy Authority at Culcheth, for example, the scientists and technicians are today testing and specifying materials for nuclear power projects which have not yet come off the drawing boards.

So when the Press announces yet another British achievement in the field of nuclear power, perhaps we should reserve a little of the praise for the scientists and technicians, the 'back room boys' who have made it all possible.

*At the service of the U.K.A.E.A. scientists—and all engaged in nuclear engineering—are the facilities of the Kodak Research Laboratories at Harrow. Here, more than 200 qualified scientists, with specialists on every side of photographic and radiographic inspection, are constantly at the service of fellow scientists and engineers. So if there is any application of photography or radiography on which you need advice and information, please write to —*

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Photomicrography is employed extensively, the main uses being in studies of the grain size and structure of proposed canning materials and of possible uranium-based fuels before and after mechanical tests and in various conditions of heat treatment. Photomicrography is also used in studies of modes of deformation of uranium. Optical and electron micrograph investigations are made of structural changes in potential pressure vessel steels.

Time-lapse cinematography is used to record the sequence of dimensional changes during the thermal cycling of uranium.

Photographic methods are used to record diffracted x-radiation during the study of crystal structures.

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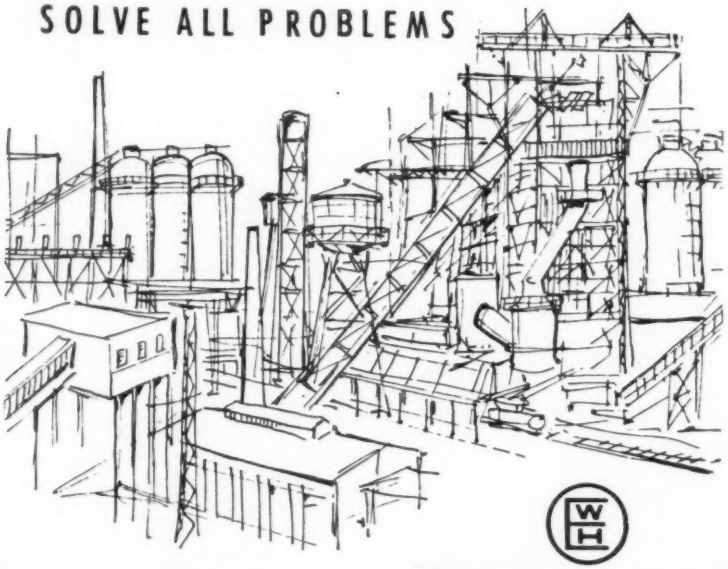

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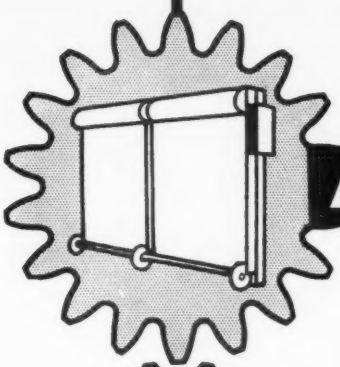
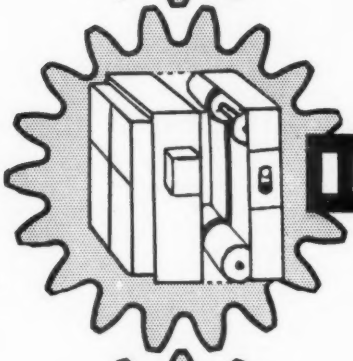


# AUTOMATION



# IN

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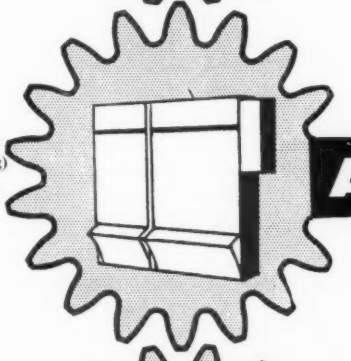
A self-maintaining filter with a renewable curtain of bonded glass fibre. More Roll-O-Matic filters are in service than any other make of filter of this type.



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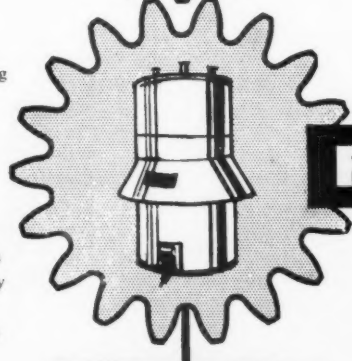

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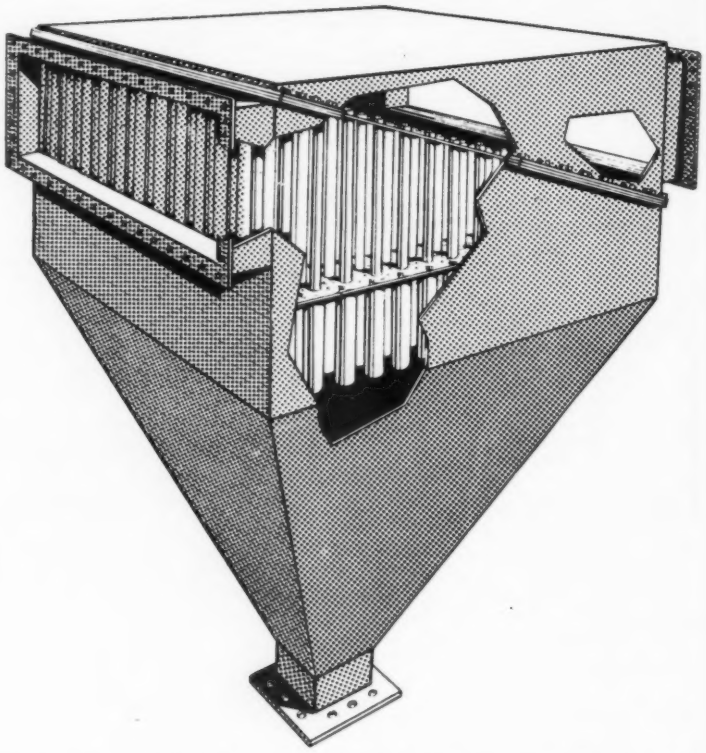

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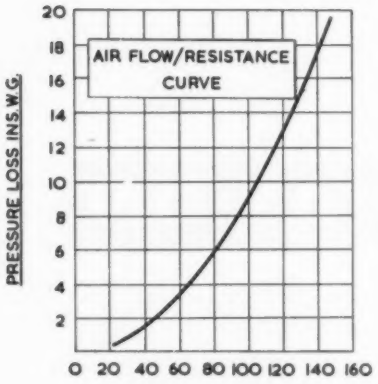
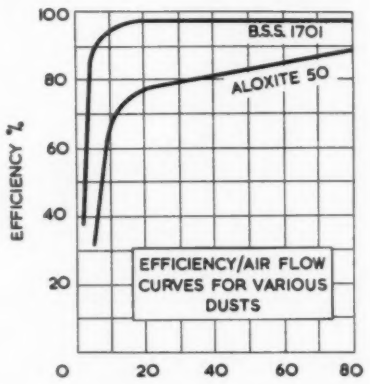
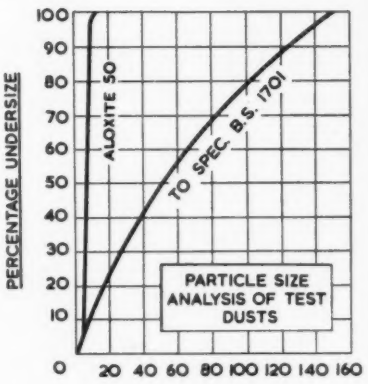
Efficient dust-collection and suppression presents many problems, particularly in the lower micron range. Now, extensive Cyclone research by Vokes' engineers has effected a radical reduction in vortex instability and bounce. The Vokes Cyclone with the 'pencil stabiliser' (patents pending) shows outstanding improvements over conventional types. We invite your dust collection and suppression enquiries.

PERFORMANCE CURVES OF VOKES MULTIPLE CYCLONE UNITS

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*Vokes (Canada) Ltd., Toronto* *Vokes Australia Pty. Ltd., Sydney* *Represented throughout the world*

V285

**SERVICE DE RENSEIGNEMENTS POUR NOS LECTEURS**

*Il est souvent difficile au client publicitaire d'indiquer dans un espace restreint tous les détails de ses produits. Dans le cas où vous désireriez de plus amples renseignements à ce sujet, veuillez pointer le numéro approprié sur la carte ci-contre et envoyer cette dernière à* NUCLEAR POWER.

**AUSKUNFTSDIENST FÜR LESER**

*Es ist oft schwierig für Inserenten alle technischen Einzelheiten über ihre Produkte in einem begrenzten Platz zu bringen. Sollten Sie noch weitere Auskünfte wünschen, streichen Sie einfach die bestimmten Nummern auf der nebenstehenden Karte an, und senden Sie sie an* NUCLEAR POWER.

**SERVIZIO D'INFORMAZIONI PER I NOSTRI LETTORI**

*E' talvolta difficile all'inserzionista di indicare in uno spazio ristretto tutti i particolari dei suoi prodotti. Qualora desideraste ricevere più ampie informazioni a questo riguardo, favorite segnare il numero appropriato sul cartellino qui accanto ed inviare quest'ultimo a* NUCLEAR POWER.

**SERVICIO DE INFORMACIÓN PARA EL LECTOR**

*Se hace a menudo difícil para los anunciantes dar en un espacio limitado todos los detalles técnicos sobre sus productos. Si desea ulterior información, marque los números apropiados en la tarjeta opuesta y mándela a* NUCLEAR POWER.

**Информация для читателей**

*Часто бывает трудно рекламирующим лицам давать все технические подробности своей продукции в рекламе. Если Вам понадобятся добавочные сведения, то просто отметьте соответствующие номера на наточке на противоположной стороне и отправьте к* NUCLEAR POWER.

讀者詢問服務

在廣告上以有限的地方來解釋一些專门技術 及它們的效果 的確是有受限制的困难若論者欲著知道一些詳細的情形就請將对面的表格 取一號下來將圈下有疑问的項目 用笔勾一寄郵寄給子能工程急即可.

讀者サービス

廣告紙面の関係上製品の技術的細目は掲載しきれません人ので詳しくは裏のカードの適當なナンバーに印をつけて原手が況拉由してすればお答へします.


**Nuclear Power**

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

*June* [redacted] *1958*

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| | | | | | |
|---|---|---|---|---|---|
| 1 | 26 | 51 | 76 | 101 | 126 |
| 2 | 27 | 52 | 77 | 102 | 127 |
| 3 | 28 | 53 | 78 | 103 | 128 |
| 4 | 29 | 54 | 79 | 104 | 129 |
| 5 | 30 | 55 | 80 | 105 | 130 |
| 6 | 31 | 56 | 81 | 106 | 131 |
| 7 | 32 | 57 | 82 | 107 | 132 |
| 8 | 33 | 58 | 83 | 108 | 133 |
| 9 | 34 | 59 | 84 | 109 | 134 |
| 10 | 35 | 60 | 85 | 110 | 135 |
| 11 | 36 | 61 | 86 | 111 | 136 |
| 12 | 37 | 62 | 87 | 112 | 137 |
| 13 | 38 | 63 | 88 | 113 | 138 |
| 14 | 39 | 64 | 89 | 114 | 139 |
| 15 | 40 | 65 | 90 | 115 | 140 |
| 16 | 41 | 66 | 91 | 116 | 141 |
| 17 | 42 | 67 | 92 | 117 | 142 |
| 18 | 43 | 68 | 93 | 118 | 143 |
| 19 | 44 | 69 | 94 | 119 | 144 |
| 20 | 45 | 70 | 95 | 120 | 145 |
| 21 | 46 | 71 | 96 | 121 | 146 |
| 22 | 47 | 72 | 97 | 122 | 147 |
| 23 | 48 | 73 | 98 | 123 | 148 |
| 24 | 49 | 74 | 99 | 124 | 149 |
| 25 | 50 | 75 | 100 | 125 | 150 |

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**Nuclear Power**

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

*June* [redacted] *1958*

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|---|---|---|---|---|---|
| 1 | 26 | 51 | 76 | 101 | 126 |
| 2 | 27 | 52 | 77 | 102 | 127 |
| 3 | 28 | 53 | 78 | 103 | 128 |
| 4 | 29 | 54 | 79 | 104 | 129 |
| 5 | 30 | 55 | 80 | 105 | 130 |
| 6 | 31 | 56 | 81 | 106 | 131 |
| 7 | 32 | 57 | 82 | 107 | 132 |
| 8 | 33 | 58 | 83 | 108 | 133 |
| 9 | 34 | 59 | 84 | 109 | 134 |
| 10 | 35 | 60 | 85 | 110 | 135 |
| 11 | 36 | 61 | 86 | 111 | 136 |
| 12 | 37 | 62 | 87 | 112 | 137 |
| 13 | 38 | 63 | 88 | 113 | 138 |
| 14 | 39 | 64 | 89 | 114 | 139 |
| 15 | 40 | 65 | 90 | 115 | 140 |
| 16 | 41 | 66 | 91 | 116 | 141 |
| 17 | 42 | 67 | 92 | 117 | 142 |
| 18 | 43 | 68 | 93 | 118 | 143 |
| 19 | 44 | 69 | 94 | 119 | 144 |
| 20 | 45 | 70 | 95 | 120 | 145 |
| 21 | 46 | 71 | 96 | 121 | 146 |
| 22 | 47 | 72 | 97 | 122 | 147 |
| 23 | 48 | 73 | 98 | 123 | 148 |
| 24 | 49 | 74 | 99 | 124 | 149 |
| 25 | 50 | 75 | 100 | 125 | 150 |

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| 7 | 32 | 57 | 82 | 107 | 132 |
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| 20 | 45 | 70 | 95 | 120 | 145 |
| 21 | 46 | 71 | 96 | 121 | 146 |
| 22 | 47 | 72 | 97 | 122 | 147 |
| 23 | 48 | 73 | 98 | 123 | 148 |
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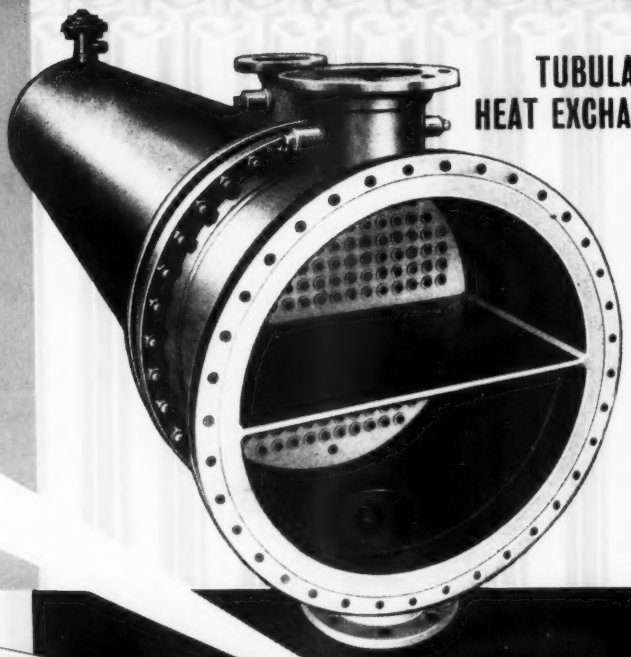
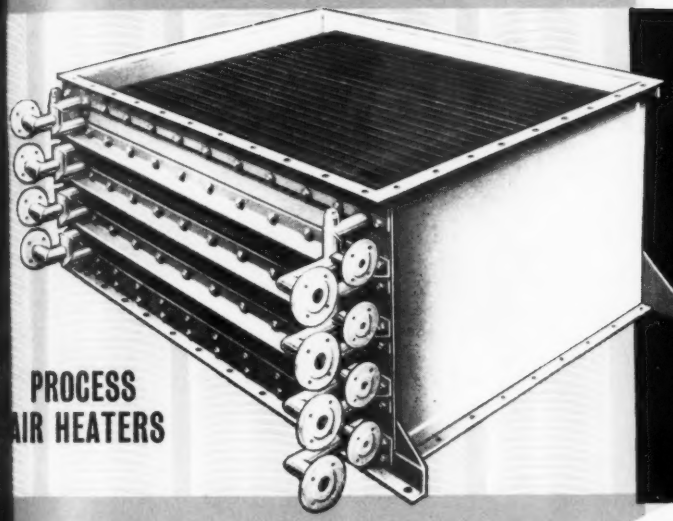
# Design
# Research
# Manufacture



TUBULAR
HEAT EXCHANGERS



PROCESS
AIR HEATERS

WELDEX
REGD.

*This Division concentrates exclusively on Heat Exchange equipment. May we give your special problem our expert attention?*

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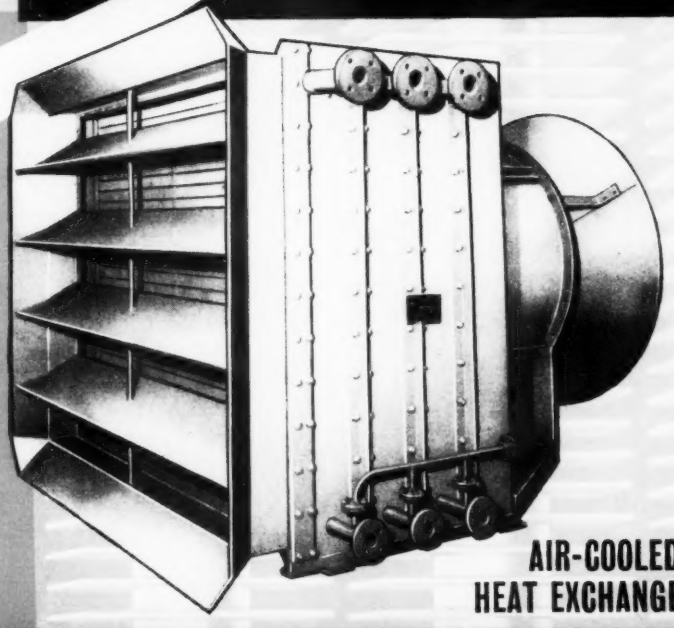
Chemical & Petroleum Engineering Exhibition
Olympia, London, 18th to 28th June, 1958



AIR-COOLED
HEAT EXCHANGERS

Heat Exchange Division
WELLINGTON
TUBE WORKS LTD

GREAT BRIDGE · TIPTON · STAFFORDSHIRE

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"THE BEST stuff is p.v.c. Not a doubt. All these suits are made with I.C.I. 'Corvic'. We've found it the most satisfactory. And I.C.I. p.v.c. polymers and compounds are backed by the finest research and technical service in the country."

*'Corvic' is the registered trade mark for the p.v.c. manufactured by I.C.I.*

IMPERIAL CHEMICAL INDUSTRIES LIMITED · LONDON · S.W.1

PC. 2

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*FIRST IN THE FIELD—AND STILL IN THE LEAD*

# LINCOLN

*Lincoln Arc Welding Equipment, Electrodes and Accessories, together with their latest Automatic Submerged Arc Welding Units, will be on display, and demonstrated, at the Chemical and Petroleum Engineering Exhibition, Olympia, London, from June 18 until June 28 — Stand Number 2A (Ground Floor).*

## LINCOLN ELECTRIC CO LTD

WELWYN GARDEN CITY · HERTFORDSHIRE

WELWYN GARDEN 920 (5 lines) 4581 (5 lines)

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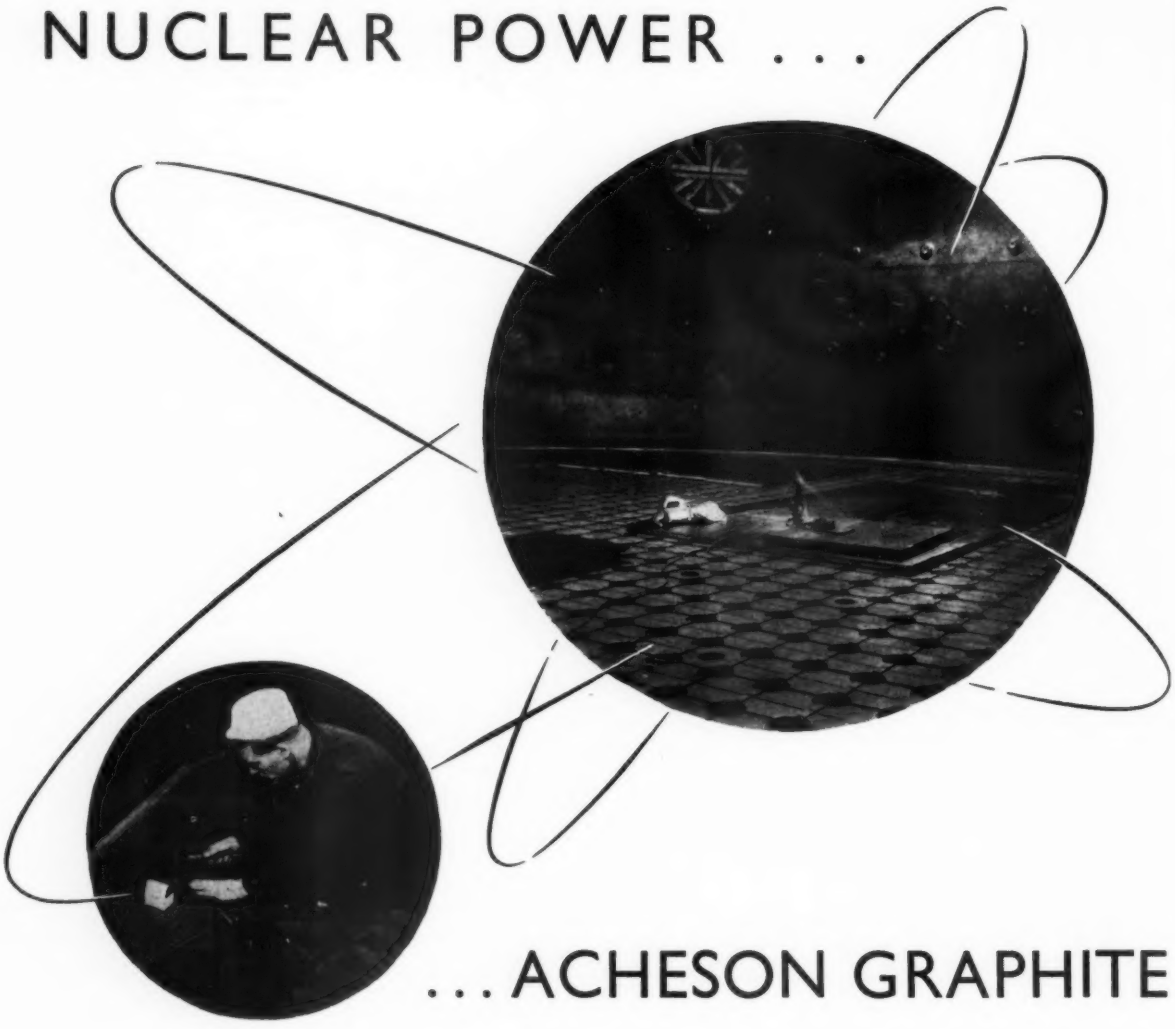
# NUCLEAR POWER . . .



# . . . ACHESON GRAPHITE

In its work as a neutron brake the pile moderator performs an exceptional role in the reduction of neutron velocities to thermal values for the continued promotion of the natural uranium fission process. In this function Acheson Graphite is playing a supremely vital part. In close collaboration with the United Kingdom Atomic Energy Authority 5,000 tons of Acheson Graphite conforming to an exceptionally strict specification for purity were supplied for the Calder Hall 'A' reactor. Many thousands more tons of Acheson Graphite in nuclear qualities are in train for Britain's Atomic Power Stations.

**ACHESON GRAPHITE**
TRADE MARK

*The term ACHESON is a trade mark.*

**BRITISH ACHESON ELECTRODES LTD., WINCOBANK, SHEFFIELD. PHONE ROTHERHAM 4836**

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## SOLID & FLEXIBLE ROLLER BEARINGS

Full range of Solid and Flexible Roller Bearings available from 10 mm. to 350 mm. shaft diameter. Ask for catalogue *RFX*
High capacity Max-Load Roller Bearings in a very wide range also available. Ask for catalogue *MAX*
All interchangeable with and equivalent to bearings of American type and manufacture.

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A37

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Two of three jig borers. Capacity 28 ins. × 28 ins.

***LET 25 YEARS EXPERIENCE SOLVE YOUR MEDIUM PRECISION ENGINEERING PROBLEMS***

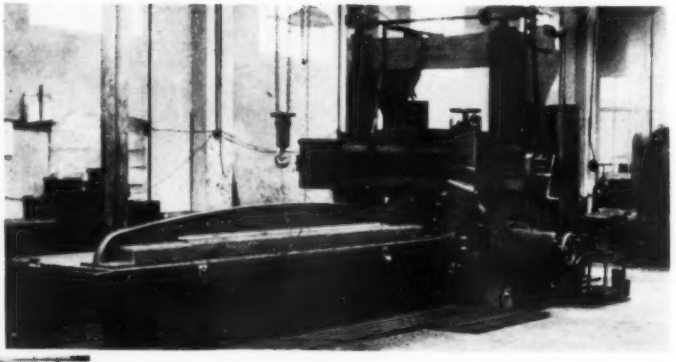
# PRECISION ENGINEERING

***PRODUCES*** ***POWER*** ***FROM***

# NUCLEAR ENERGY

CONTRACTS COMPLETED FOR—

NGTE PYESTOCK
AERE HARWELL
AWRE ALDERMASTON



Planing machine capacity 16 ft. × 5 ft. × 5 ft.

In parallel surface tables 24 ft. × 5 ft.

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AID & ARB APPROVED.
ALL WORK CHECKED BY MICRO-ALIGNMENT TELESCOPES AND ACCESSORIES.

*All work undertaken in a spacious modern factory where a large expansion programme is in progress.*

**AERO PRECISIONS LTD.**

**WATERWORKS ROAD**
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**Phone : Cosham 76832-3**

**DRAKELOW 'B'**
(1-120 Mw Reheat units)

**AGECROFT 'B'**
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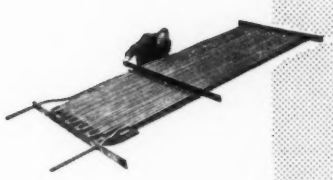
**HIGH MARNHAM**
(5-200 Mw Reheat units)

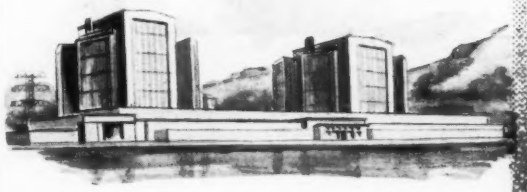
**2—275 Mw REHEAT UNITS**
**and**
**1—550 Mw REHEAT UNITS**

which represent the ultimate expression in the development, research, manufacturing and field experience with steam superheaters is brought to the Nuclear field through

**HUNTERSTON***



* *Checking the precision level of a special Superheater element as supplied to Hunterston.*



The SUPERHEATER COMPANY LTD
53 HAYMARKET LONDON S.W.1

*the authority on superheated steam*

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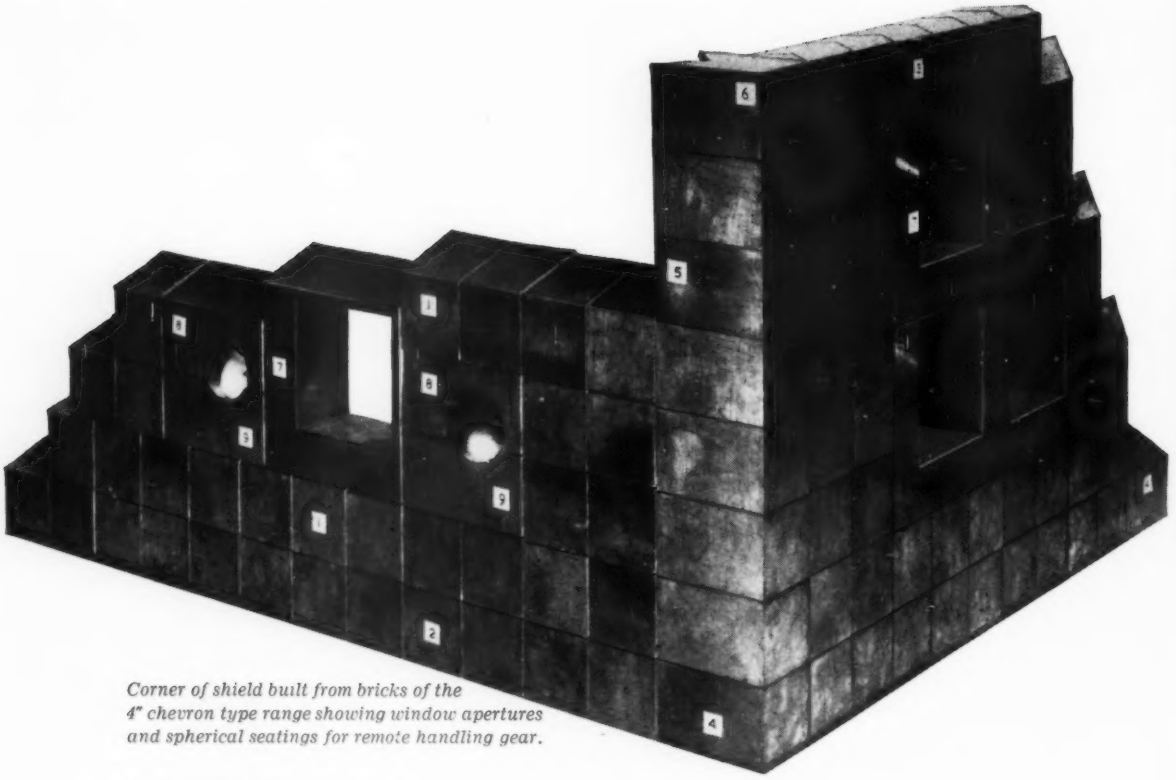
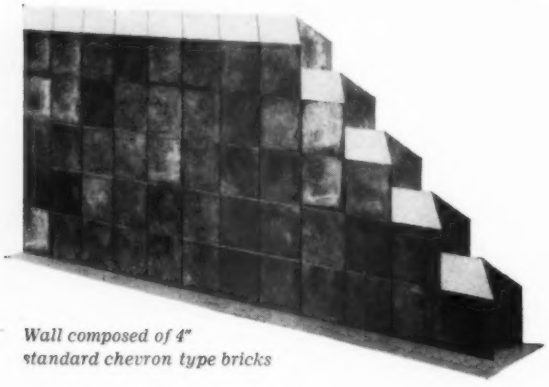


*Corner of shield built from bricks of the 4" chevron type range showing window apertures and spherical seatings for remote handling gear.*



*Wall composed of 4" standard chevron type bricks*

# LEAD SHIELDING

Some of the lead bricks we supplied to the United Kingdom Atomic Energy Authority are shown in these photographs. The people to consult about the production of special shapes for shielding are Associated Lead.

**ASSOCIATED LEAD**

MANUFACTURERS LIMITED

CLEMENTS HOUSE, 14 GRESHAM STREET, LONDON, E.C.2
CRESCENT HOUSE, NEWCASTLE
LEAD WORKS LANE, CHESTER

EXPORT ENQUIRIES: ASSOCIATED LEAD MANUFACTURERS EXPORT CO. LTD., CLEMENTS HOUSE, 14 GRESHAM STREET, LONDON, E.C.2

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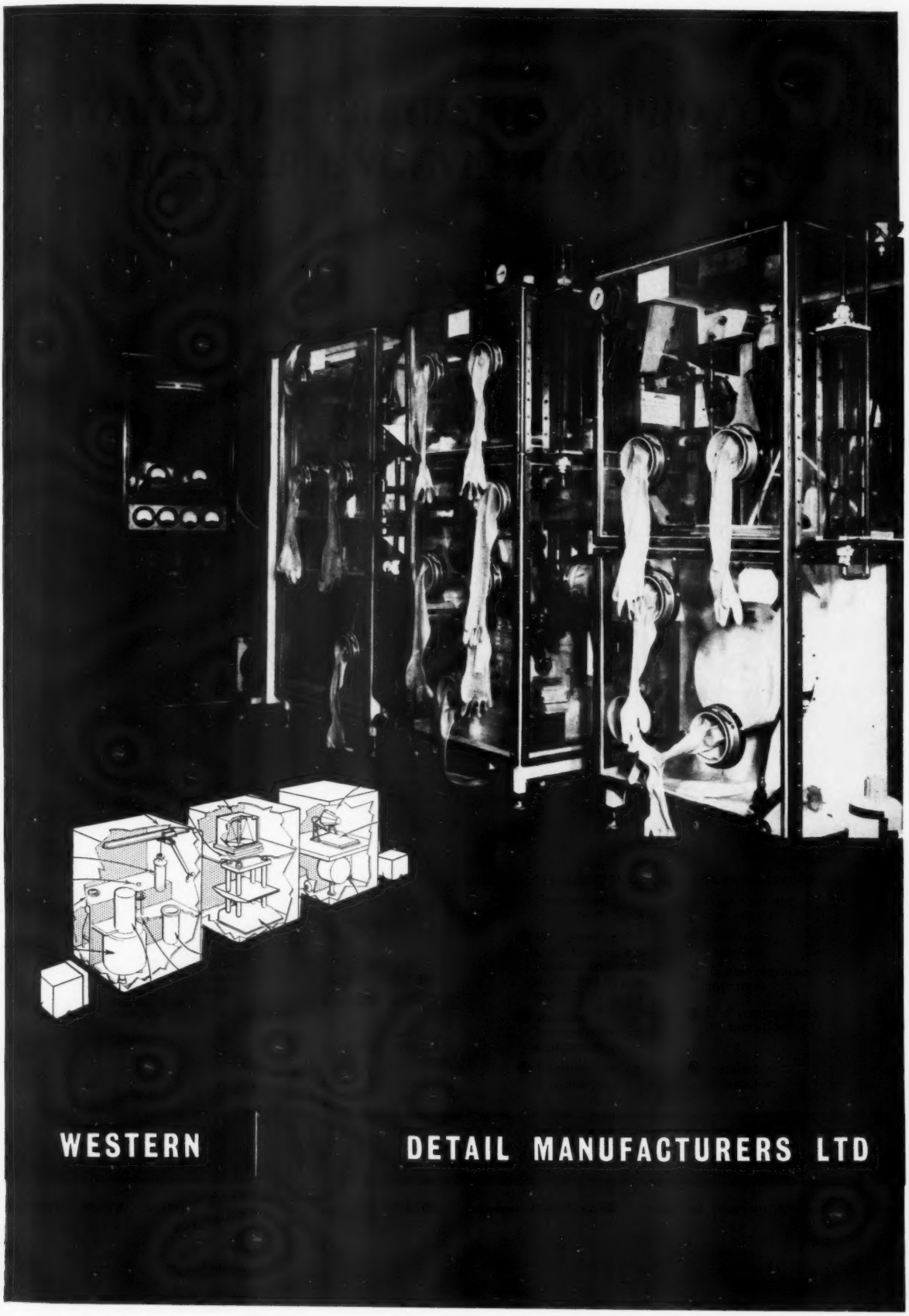

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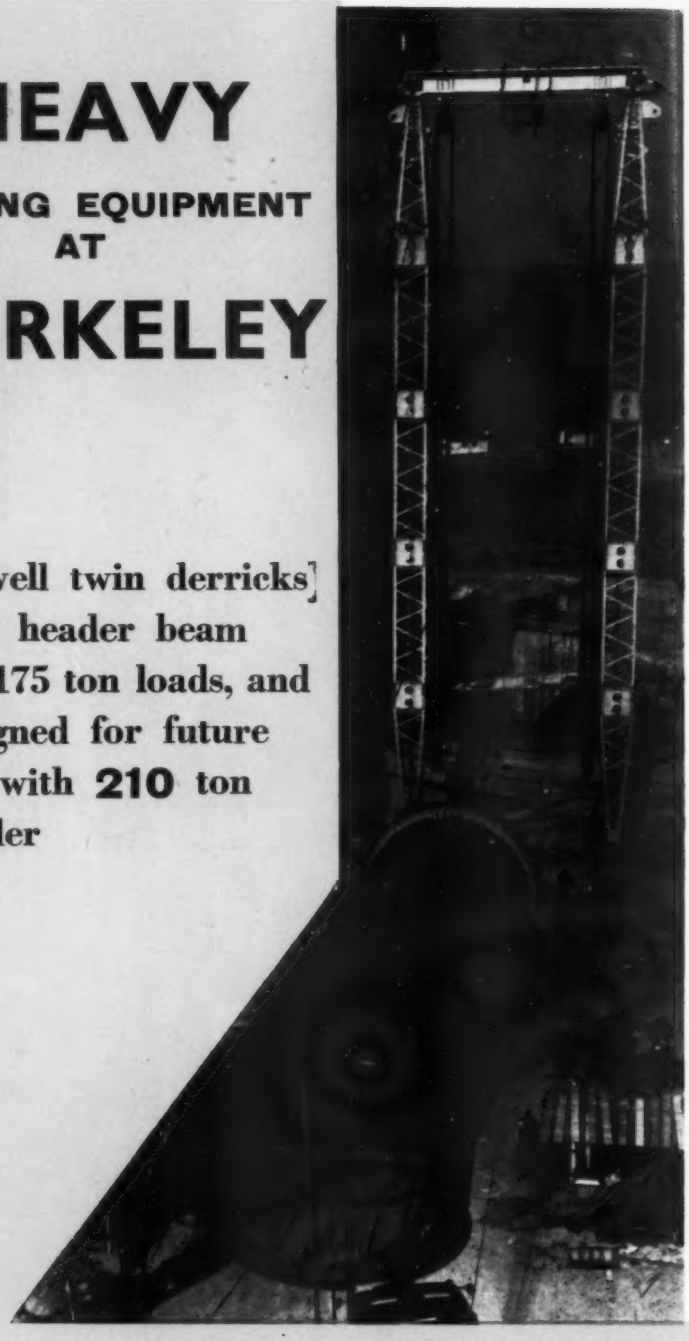
# HEAVY

## LIFTING EQUIPMENT AT

# BERKELEY

**Caswell twin derricks with header beam for 175 ton loads, and designed for future use with 210 ton header**



**Lattice erection masts and guy derricks of all heights and capacities with electric or diesel single or multidrum winches designed and manufactured for SALE or HIRE**

*Photographs reproduced by permission of Messrs. John Thompson Ltd. and U.K.A.E.A.*

**CASWELL** Cranes & Erection Ltd

GROVE WORKS HAMMERSMITH LONDON W. 6 Phone RIVERSIDE 8922/5

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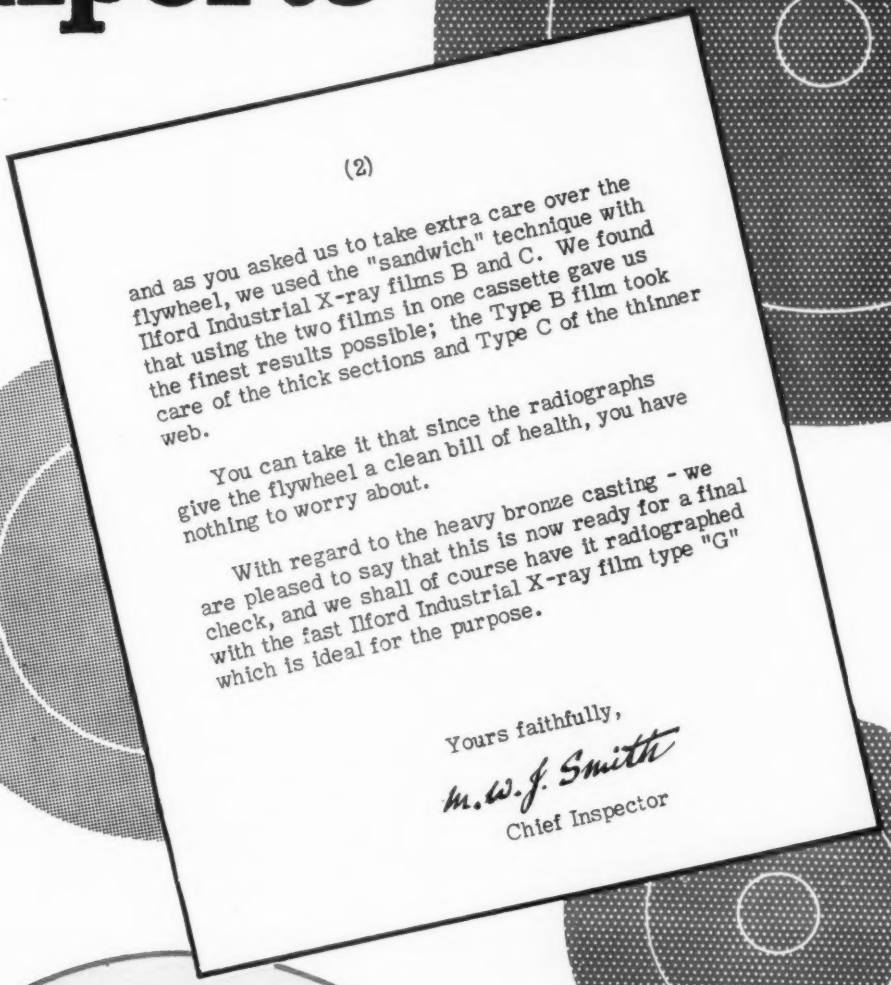
# Between experts



(2)

and as you asked us to take extra care over the flywheel, we used the "sandwich" technique with Ilford Industrial X-ray films B and C. We found that using the two films in one cassette gave us the finest results possible; the Type B film took care of the thick sections and Type C of the thinner web.

You can take it that since the radiographs give the flywheel a clean bill of health, you have nothing to worry about.

With regard to the heavy bronze casting - we are pleased to say that this is now ready for a final check, and we shall of course have it radiographed with the fast Ilford Industrial X-ray film type "G" which is ideal for the purpose.

Yours faithfully,

*m.w.j. Smith*

Chief Inspector

**ILFORD**

**X-RAY FILMS**

**FOR INDUSTRIAL RADIOGRAPHY**

*ILFORD LIMITED · ILFORD · ESSEX*

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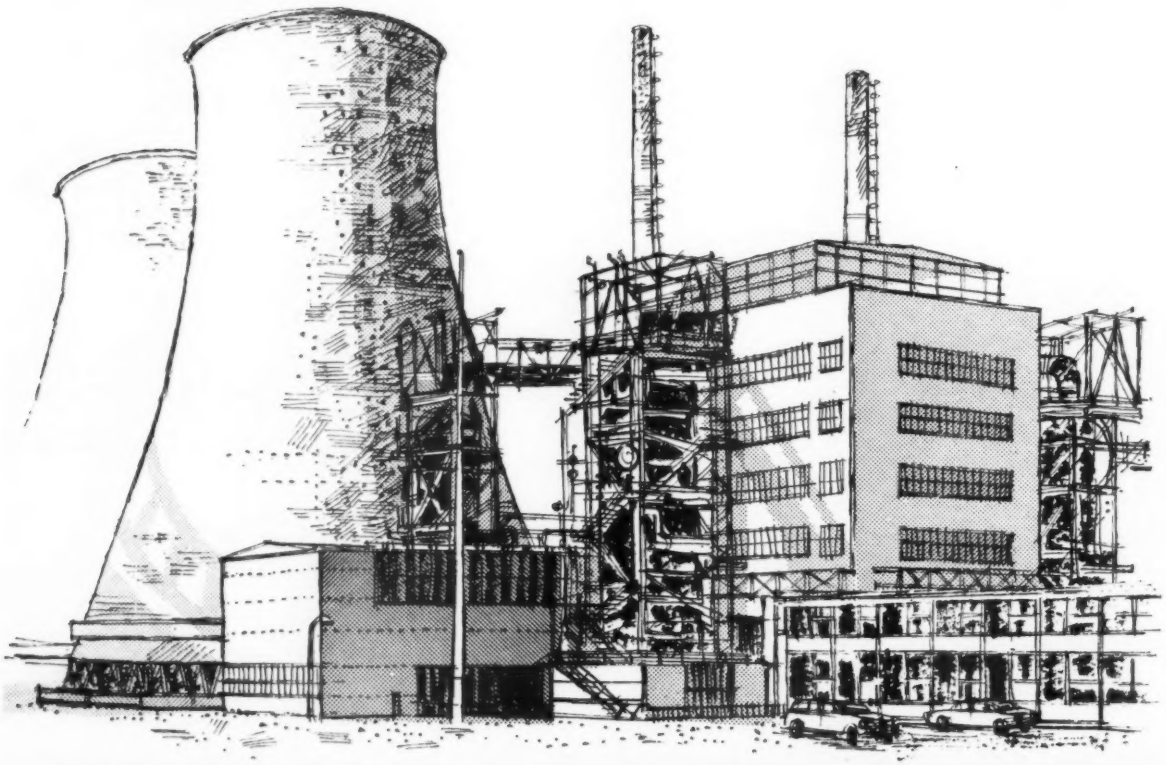
SERCK

nisation

is actively concerned in the supply of equipment and material with special application to the Nuclear Power Industry



Primary and Secondary surface heat exchangers, Condensers, Air and Gas coolers, Condenser tubes

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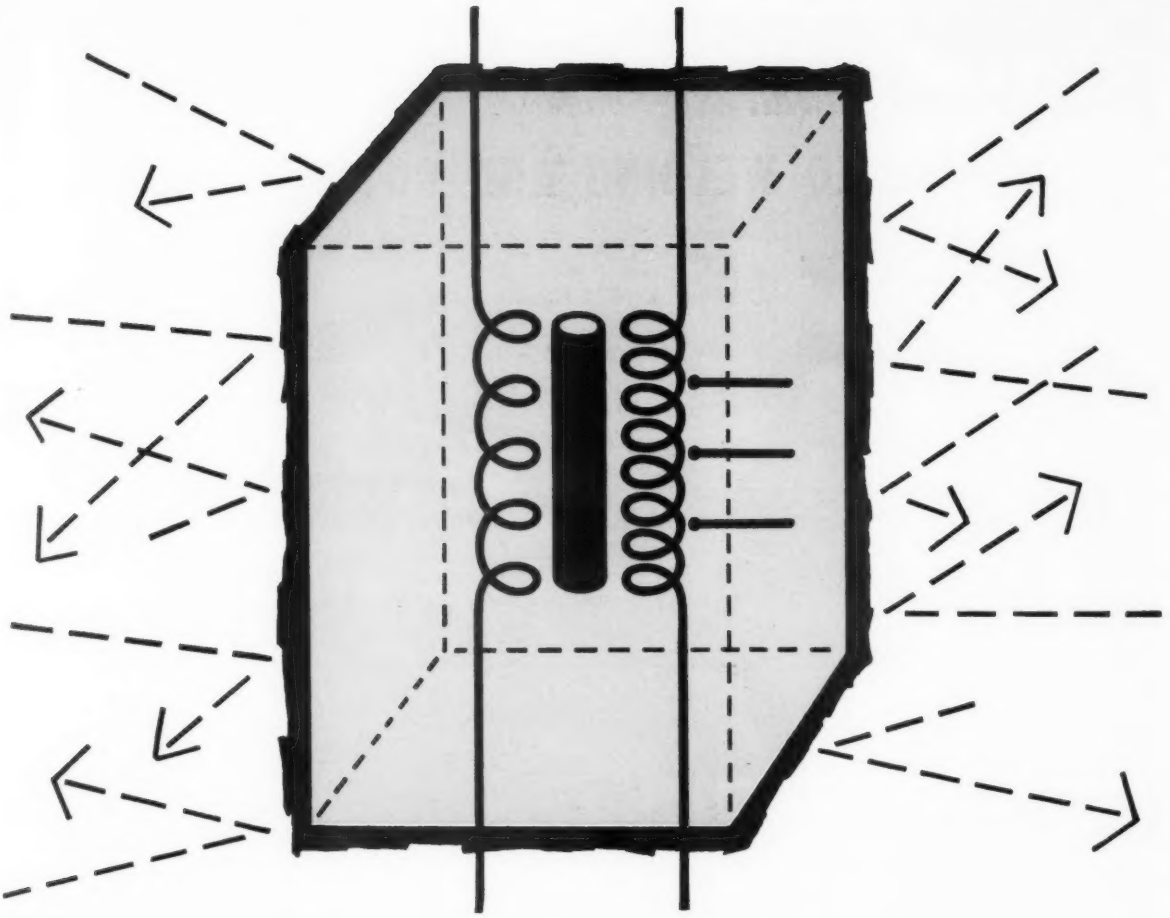

## Resistant to mechanical shock, vibration, moisture, corrosion

The potting of capacitors, chokes, delay lines and similar components, as a protection against mechanical and vibrational shock, moisture and corrosion, demands a potting material which possesses an exceptional combination of properties. Epikote resins provide this combination outstandingly: a high degree of adhesion to metals and other materials, with minimal shrinkage on cure; toughness; resistance to thermal cycling; excellent electrical properties over a wide temperature range (i.e. high dielectric strength, low power factor and high volume resistivity and arc resistance). It is not surprising that Epikote resins have won wide acceptance in the electrical industry. Ask for full details.

EPIKOTE EPOXY RESINS for perfect potting

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*Divisional Offices:* LONDON: Norman House, Strand, W.C.2. Tel: TEMple Bar 4455. BIRMINGHAM: 14-20, Corporation Street, 2. Tel: Midland 6954-8. MANCHESTER: 144-6, Deansgate. Tel: Deansgate 6451. GLASGOW: 124, St. Vincent St., C.2. Tel: Central 9561. BELFAST: 35-37, Boyne Square. Tel: Belfast 26094. DUBLIN: 53, Middle Abbey Street. Tel: Dublin 45775.

EE.4

*"EPIKOTE" is a Registered Trade Mark.*

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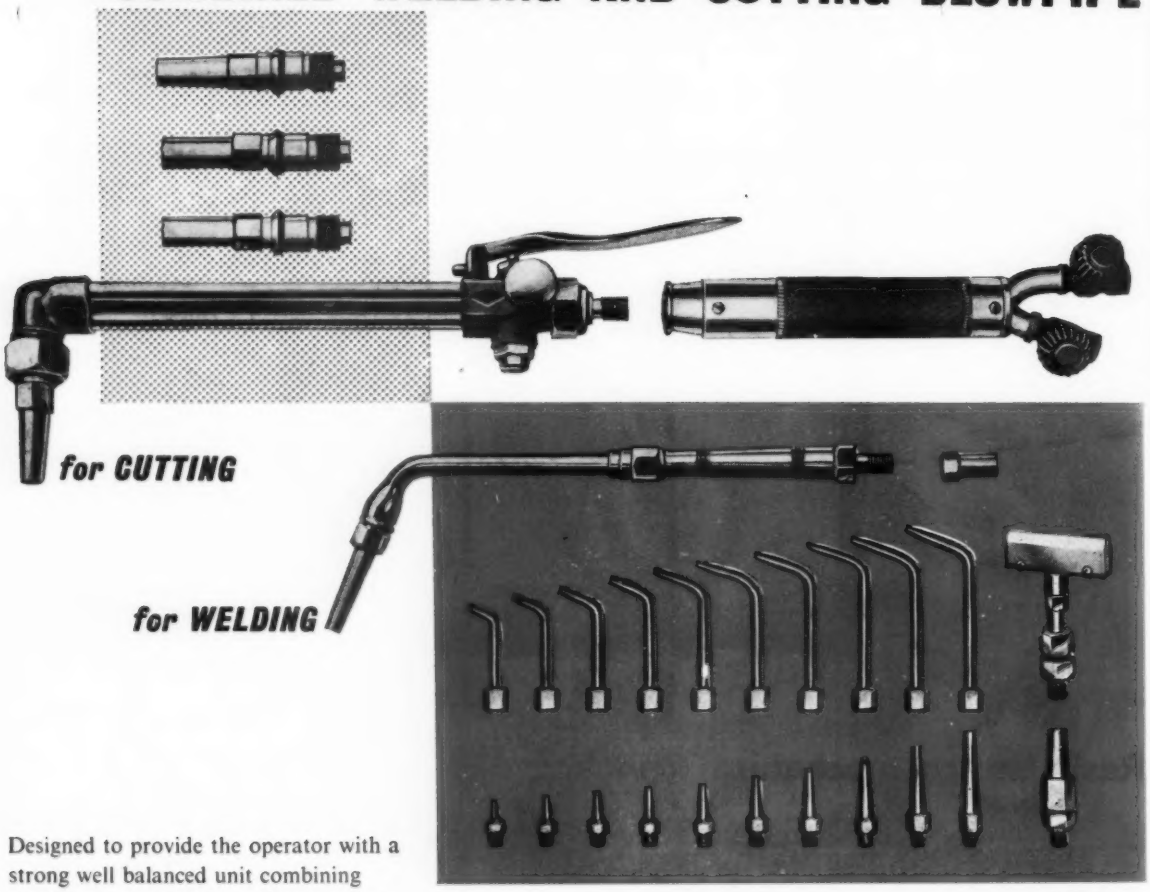
*maintaining* ***B.I.G.*** *excellence*

# COMBINED WELDING AND CUTTING BLOWPIPE



***for CUTTING***

***for WELDING***

Designed to provide the operator with a strong well balanced unit combining maximum power with maximum safety.

Based on many years' practical experience, design of B.I.G. cutters incorporates the following unique features:

***Cupro nickel gas tubes***

***Silver solder joints***

***Nozzle mixing of gas which is best deterrent to flashback***

***One-piece solid copper nozzle***

***Special high pressure oxygen seats***

HARRIS DESIGN

*... and built to* ***B.I.G.*** *standards*

## British Industrial Gases Limited

**700, GT. CAMBRIDGE RD, ENFIELD, MIDDX.** Telephone: **ENField 4022,** Telex: **24128**

*Sales and Technical Assistance available in most areas*

Rainbow 1754

# I.C.I.

# supplies Carbon Dioxide

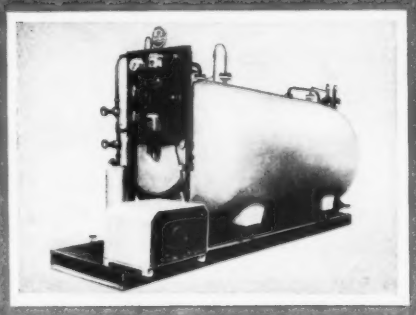
# to CALDER HALL

CO

Regularly every week, road tankers of eight-ton capacity deliver liquid carbon dioxide in bulk to the reactors at Calder Hall. At intervals, demands for extra quantities are met at a few hours' notice. I.C.I.'s express delivery service ensures that vital work is never delayed.

I.C.I. supplies storage tanks of five-ton capacity *complete and ready for use*, and offers advice on the design of special-purpose tanks of greater capacity.

A full technical service is available on the installation of storage tanks, and on all other aspects of the handling, distribution, and use of carbon dioxide.



Without effort and without loss, I.C.I. carbon dioxide, which meets the exacting requirements of the U.K. Atomic Energy Authority, is always on tap, where and when it is wanted.

$CO_2$

ICI

*Full information on request*

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.1

BE.281

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## The name of KENT has dominated power-station instrumentation since the 1920's

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**Nuclear Power**
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

**JUNE 1958 VOLUME 3 NUMBER 26**

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# Publishers Column

## New Look

With this issue NUCLEAR POWER is into its third year. We have come a long way since May 1956 and learned a good deal about the way readers like their nuclear material presented to them. Regular subscribers have probably noticed that from time to time we have introduced new features and given others a new look. This is as it should be—no really live publication remains completely static. As the field widens and more information on new topics becomes available, the magazine has to adapt itself to carry them.

So the occasion of our second birthday seemed a good time to have an overall review of the look of NUCLEAR POWER—in fact, to have a spring clean. We had a meeting of the editorial, production and art departments which lasted for several hours, and the results are incorporated in this issue. We hope you think they are an improvement too.

It may be that you think the appearance of a magazine is secondary, that what matters is what the words say, not how they are arranged on a page or the type face used for the headings and titles. Although we certainly agree that the most important part of the magazine is its content, we firmly believe that the art department can make it much easier to read and more pleasant to look at—as well as simpler to find your way about in. This is, of course, especially important for someone seeing the magazine for the first time —he must be able to see at a glance what every article and news section is about. But in our opinion this also has an effect —perhaps subconscious—on the reader who sees the magazine every month.

From time to time we are accused of 'looking American.' While we take this as a compliment because on the whole transatlantic publishers make a much better job of producing lively-looking technical magazines, we think it is an unjustified one. Nevertheless, we believe that British technical publishing could do with a facelift and we will continue to do everything possible to bring it about.

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# Shell lends a hand at Dounreay

Lubrication conditions at Dounreay are particularly severe. As the site is too remote to tap the National Grid, the nuclear research installation is completely dependent on the 200 b.h.p. diesel electric sets. These sets *will have to be absolutely dependable at all times*. There is no second string.

Absolute dependability being largely a question of correct lubrication, the Atomic Energy Authority called in Shell for advice. After comparative lubrication tests, the A.E.A. chose Shell RIMULA Oil 30—a very heavy duty oil.

The moral of the Dounreay story is that Shell can work with even the most specialised sectors of industry to provide the right oil for the job. If dependable lubrication is your problem, it pays to get in touch with Lubricants Department, Shell-Mex & B.P. Ltd., Shell-Mex House, Strand, London, W.C.2.

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# SIR! LETTERS TO NUCLEAR POWER

## Our welding symposium

SIR: May I extend my heartiest congratulations to NUCLEAR POWER for its initiative and imagination in publishing the Welding Symposium in the May issue.

Being responsible for the design of welded nuclear equipment, and having taught at a Technical College, I fully endorse the views so ably and pungently expressed by Dr Weck, Director of the British Welding Research Association. In my view, his introduction should be reprinted and circulated to every appropriate technical educational authority in this country.

As a member of the Institute of Welding, I also trust that this issue will result in wider recognition and a real measure of support for a body which plays a vital part in the success of this country's engineering activities.

J. A. MARSH
Manager and Chief Engineer
*Nuclear, Mechanical and Chemical Division,*
*A. C. Wilson & Partners Ltd, London W5*

▶ *This is an excellent idea and we shall certainly reprint Dr Weck's introduction and circulate it as Mr Marsh suggests.* *Ed.*

## Information please

SIR: Could you bring me up to date in a short note on the present situation of nuclear power in the U.K.? As I understand it, Calder Hall, which I saw last year, has its third reactor operating and the fourth is to come in this year to give a total of 181,000 kW into the power grid. At what stage are other plants under construction, and what contracts are pending with the capacity of the plants concerned ?

*The Northern Miner,* RICHARD PEARCE
*Toronto 1, Canada*

▶ *Your Calder facts are corrrect. The next station to come into operation will be Chapel Cross—an Atomic Energy Authority station practically identical with Calder. Its first reactor is due for operations in the autumn, with the other three following at four-month intervals. Four large power stations are under construction as follows: Berkeley, Gloucestershire (275MW) — started Jan 57, due complete end 60; Bradwell, Essex (300MW)—started Jan 57, due complete end 60; Hunterston, Ayrshire (320MW)—started Aug 57, due complete 61; Hinkley Point, Somerset (500MW)—started Sept 57, due complete 61. The next station will be in Wales but the contract has not yet been let.* *Ed.*

## Miniaturized components

SIR: I was extremely interested in Mr Nayler's comments on the reliability of miniaturized components. I take Mr Nayler's point that if a fault occurs the assembly may be replaced complete if miniaturized techniques are used, but it is of course true that if the same methods of construction were adopted when using larger components faulty units could still be replaced readily.

The weight and volume occupied by the units would naturally both be somewhat larger when using non-miniaturized components, although not inconveniently so in power system applications.

It will be readily appreciated that every equipment fault is a potential hazard to the reliable operation of the reactor in service despite the fact that quite elaborate steps are taken to reduce this hazard so far as


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practicable by the provision of coincidence circuits. The ready replacement of a defective assembly is poor consolation if a fault or a combination of faults has in fact tripped the reactor. The design requirement is, therefore, a minimum number of faults, both for economic reasons and also because this will represent the minimum hazard to reactor availability.

I should appreciate an opportunity to consider any information which Mr Nayler can make available to me on the relative reliability, under appropriate conditions, of miniaturized and other components, but pending satisfactory further evidence I feel I must repeat my statement that 'if the incorporation of miniaturized components in power station nucleonic equipment results in decreased reliability of operation then this is too high a price to pay for the saving of space and the easier mechanical handling of a unit, which are generally the only advantages resulting from miniaturization applied to power station instrumentation.'

My own experience suggests that in general miniaturized components have a shorter life than larger components of comparable quality, and this is particularly relevant in cases where they dissipate energy.

*Central Electricity Generating Board, London, SE1* B. C. GODBOLD

## String and sealing-wax

SIR: I would like to support the views of Mr L. R. Storey (*Sir*, May). I was faced with the decision whether to be at both Physical Society and Instruments Electronics Automation Exhibitions and decided to drop the former.

In its original form the Physical Society is adequate for the purpose: as another commercial exhibition it is outmoded by the I.E.A. because the latter is better advertised, is a better advertisement for British enterprise, is more internationally flavoured, has vastly superior amenities for visitors (and exhibitors) and—most important—one can have more than two people viewing ones products simultaneously, and in comfort.

Yes, back to baize and boffins at the Physical Society I say.

*Southern Instruments Computer Division, Camberley, Surrey* W. B. HORNER Sales Manager

SIR: I am very much in agreement with Mr Storey's opinions about the Physical Society Exhibition (*Sir*, May). It is sad to see how the emphasis has switched to sales, prices and delivery dates and how instruments are shown in neatly packaged and productionized form instead of 'in the white'. This should be a place where ideas can be exchanged between the exhibitor and the visitor, where the user can tell the manufacturer what he wants and how instruments could be developed to meet his requirements. If the instrument is held together by a piece of wire and does not function properly first time, it should not matter. As Mr Storey says, it's the idea that counts.

*Fleming Radio (Developments) Ltd Stevenage, Herts* T. H. PATTINSON Chief Development Engineer

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Nuclear Power
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JUNE 1958 VOLUME 3 NUMBER 26

## A Firm Foothold

With the signing of the collaboration agreement between the Nuclear Power Plant Co and AGIP Nucleare, and the impending contract between them for the SIMEA (Società Italiana Meridionale per l'Energia Atomica) together with the receipt of tender designs by the SENN (Società Elettronucleare Nazionale) group for the ENSI (Energia Nucleare Sud Italia) station and the ratification of the Anglo-Italian governmental bilateral agreement on fuel and technical cooperation, the nuclear picture in Italy has now come into something like focus although the power plans of the other two big Italian groups SORIN (Fiat and Montecatini) and SELNI (Edison) are by no means clear yet. What is certain however is that the first export power station in the world to be actually started—the SIMEA project—will be of British design and will incorporate much British equipment and materials. This is a remarkably fine achievment and justification of faith in the natural uranium approach and has led to a unique arrangement for carrying out the work which might well set a pattern for further agreements of this type between British and overseas firms.

Attention will now be directed to the key SENN project for which World Bank assistance is promised. Tenders for this were received by April 30 and are understood to include four British, four American, two French and one Canadian. Some of these are believed to be for relatively untried designs and cannot be given much chance. The main contenders are: the AEI-John Thompson Co, the English Electric, Babcock & Wilcox, Taylor Woodrow group and the GEC, Simon-Carves group with British gas-cooled reactors, America being represented by the GE Dresden-type boiling water reactor and the Westinghouse pressurized water unit typified by Shippingport. Thus for the first time British and American designs are brought face to face in open competition to the same specification and clearly much will depend on the outcome. On technical grounds Britain must be considered to have an excellent chance for two reasons. Firstly, AGIP Nucleare have already chosen a British station after detailed study of American proposals and if this choice is economically justified for one Italian company—as one must assume it is—then there is a good probability of SENN arriving at the same conclusions. Secondly, it is well known that although Japan has been relentlessly pressurized by the Americans to settle for one of the power plants she has indicated a clear preference for the British approach and has called for three tenders to be received by July 31.

The British heavy nuclear industry has come in for some criticism recently on its lack of thrust in obtaining export orders but we feel that this is quite unjustified in view of the above facts. It is not the British way to crow about something until it is signed, sealed and delivered and our enquiries have shown that the British groups are in fact in the throes of some very interesting developments abroad which will be revealed in due course.

As in all big business, however, there are never grounds for complacency and although we may congratulate ourselves on gaining footholds in Italy and Japan, keen competition from America lies ahead. It is now apparent that economically competitive fission power in the United States is a long way off and the big American reactor companies are anxious to do their development work abroad. Thus extremely attractive long-term credits are being freely offered through the Export/Import Bank and other agencies to countries interested in American reactors. This is something which industry cannot handle on its own and if we are to continue the good work now started in Italy, the Government must play its part. With so many demands on export credits this is an unenviable task but the fact is that export nuclear power stations are now no longer a technical problem—only a financial one.

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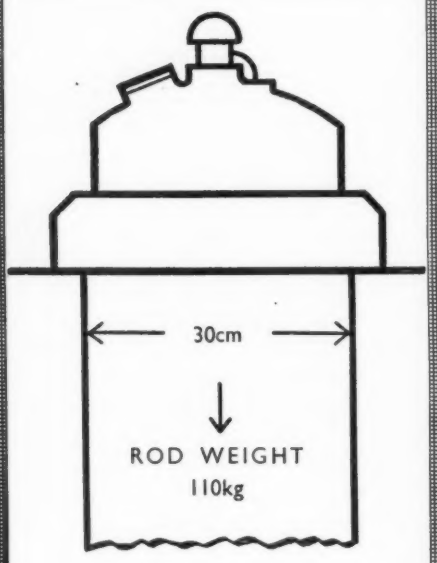


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# WORLDVIEW

## NPPC signs with AGIP

A further stage in the negotiations for the sale of a nuclear power station to Italy was reached in London on May 2 when Sgr. E. Mattei, president of the state-owned AGIP Nucleare and its parent organization, the Ente Nazionale Idrocarburi (ENI), and Sir Claude Gibb, chairman of the Nuclear Power Plant Co signed a long term 'Agreement for Collaboration.' The signing of the contract for Britain's first nuclear power station export is expected to follow in a few weeks.

The Agreement provides for cooperation in the building of nuclear power stations in Italy over a minimum period of seven years and covers the exchange of information on research, design, construction and operation and the training of technical staff. It confirms the first letter of intent received by the NPPC last November (*Worldview*, December) after negotiations lasting since the previous April. The UK Atomic Energy Authority has been in the picture at all stages and will continue to act as consultant.

The 200 eMW single graphite-moderated gas-cooled reactor will be sited at Latina about 50 miles south of Rome, instead of as originally proposed, in the north of Italy. Reasons are the greater need for electricity in the south and the unemployment problem there. It will be constructed by the Società Italiana Meridionale per l'Energia Atomica (SIMEA), a company 75 pc controlled by AGIP. Work will begin in a few weeks and the station should be in operation by the summer of 1962. About eight NPPC engineers have already moved with their families to the AGIP offices in Milan to cooperate on adapting the Bradwell type design to the particular requirements of the area and to Italian standards, and Italian engineers are studying techniques in the NPPC offices at Knutsford.

After the signing of the agreement Sir Claude Gibb said that the capital cost of the first station would not be known until the site had been surveyed in detail, but it would probably be something over £M20, of which more than half would be spent in Italy. In future stations the proportion would be still larger. Power produced would be directly competitive with that from conventional stations.

AGIP Nucleare will undertake the civil engineering and building work in close cooperation with the NPPC and will also be in charge of the manufacture and testing of all components made in Italy. The British company will be responsible for the overall design of the station and for its satisfactory commissioning and will supply the major components including the reactor with its ancillary equipment, the heat exchangers and the turbines. The pressure vessel, about 67 ft in diameter, will be made of 'orange-peel' segments pressed in Britain, of British steel, and will be welded together on site. Italian steel may be used in future stations. The British engineers now in Milan are helping to establish Italian standards for the pressure vessel, corresponding broadly to the Lloyd's inspection standards used at Bradwell. Other components will conform to Italian practice where necessary. The generators will also be made in the UK. Though mainly conventional they require certain special features for nuclear work and there is insufficient time to train Italian manufacturers to build them for this first station.

This handshake between Sir Claude Gibb and Sgr E. Mattei seals the agreement for collaboration in building nuclear plants in Italy, while Sgr G. Martinoli, managing director of AGIP, looks on

### Frank negotiations

Sir Claude stressed that the negotiations have been conducted with great frankness and that the agreement reconciles the interests of the British concerns and Italian industries. He pointed out that British industry is trying to amortize the huge expenses met in the nuclear research field by selling its products in the greatest possible number of foreign markets. On the other hand, it is aware that the importing countries not only want to solve the problems of electrical energy supply but wish to be able to master the necessary techniques to construct their own nuclear power stations in the future. 'Only someone with a restricted outlook', he said, 'would fear the outcome of our reasoning and think our efforts pointless, and that we supply our competitors with arms with which to fight against us.' Long experience has shown that foreign industries would reach their goal in any case and 'if we refuse to help them other industrial countries would very gladly take our place.' But 'if our work in assisting them technically is far seeing and thorough, the ties which are established with foreign industries are bound to last and eventually strengthen and, even if we have to give up the supply of simpler and less specialized plant we can always hope to exercise our influence by selling the more complex products, that is, the fruits of our researches and brains.' Sir Claude also emphasized that the more help which NPPC gives to AGIP the better will be the prospects of the two companies in the future 'even if we cannot expect AGIP to build all the stations for Italy's target of 2000 eMW by 1967 in collaboration with NPPC.' It would be impossible for AGIP to handle all of that, but nevertheless 'we do look forward to a large share of it.' He added that the company would be free to tender for stations required by other Italian organizations, but as a matter of common sense would work with AGIP as far as possible. It had not tendered for the ENSI project (*Worldview*, May).

### Government pact ratified

The Anglo-Italian agreement providing the necessary framework for the ex-

port of nuclear power stations came into force on May 12 with the exchange of instruments of ratification at the Foreign Office in London between Mr Selwyn Lloyd, Foreign Secretary, and Sgr Zoppi, Italian Ambassador in London. The agreement will remain in force for ten years and provides for the supply of both power and research reactors, with the necessary nuclear fuel. It also covers the exchange of unclassified technical information, the possibility of assistance being provided from Britain for the construction in Italy of plants for manufacturing fuel elements and processing used fuel, and the provision of training facilities in the UK. The agreement contains safeguards to make sure that materials and equipment supplied under it cannot be used to make weapons.

The signing of another atomic energy agreement—this time with Japan—is expected soon. It is reported that a compromise has been reached on the question of UK responsibility concerning accidents caused by nuclear fuel supplied to Japan.

## ZETA mystery clears

Recent experiments at Harwell on ZETA have proved that most of the observed neutrons, although arising from fusion are not of thermonuclear origin. Announcing this in London on May 16, Dr B. F. J. Schonland, Director of AERE, said that two physicists, Rose and Taylor, had measured the energy of the neutrons using a cloud-chamber technique. They found that the majority were emitted during fusion between very energetic deuterons (about 20 keV) and slow ones and were thus not truly thermonuclear. Dr Schonland said it was still not clear just how the deuterons received such high energies, some ten times greater than he would expect from purely resistance heating but they seemed to be associated with the beginning of the current pulses. He recalled that in the early experiments, neutron yields were about 20 times that which would have been expected if they were of thermonuclear origin. The Director said this latest work did not make the earlier results any less significant and in fact would prove of great value. He saw no reason to doubt that when pulses 100 times longer than those now achieved on ZETA are reached, this would give all the deuterons time to reach thermal equilibrum and so give ideal thermonuclear conditions.

Dr P. Thonemann, head of Harwell's CTR division said that modifications to ZETA now taking place would raise current from 200,000 amps to one million and the time of the pulse from a few thousandths of a second to 1/10 of a second. With these, spectroscopic temperatures of 10 million degrees are expected, at which point true thermonuclear results should be clearly seen. Parallel to this a new series of experiments are planned using a variety of much smaller apparatus.

## CEGB to have reactor expert

The CEGB has created a new position—that of nuclear plant design engineer—whose job will be to liaise with the manufacturing groups and the Atomic Energy Authority. It will be filled by H. H. Gott who will move from his present post as chief engineer of reactor design in the industrial power branch of the Authority.

Educated at Alsop High School, Liverpool, and Clare College, Cambridge, Mr Gott served a year with the Automatic Telephone Co before joining Power Jets Ltd as junior engineer in 1940 where he

GOTT
Will advise nuclear groups

remained four years and then moved to the Cierva Autogiro Co. In 1945, he worked on marine gas turbines at the Admiralty Engineering Laboratory and then joined the Control Commission for Germany. He moved to the Ministry of Supply at Risley in 1946 as technical engineer working on gas cooled reactors. As chief technical engineer he was concerned with the Windscale reactors and the Capenhurst plant before becoming assistant chief engineer on the fast reactor project. With the initiation of the nuclear power programme he was appointed industrial liaison engineer for the Atomic Energy Authority and was promoted to his present post as chief engineer in January, 1957.

## Atomic safety committee set up

The Atomic Energy Authority is to be advised on training in radiological protection by a safety committee set up under the chairmanship of Sir Douglas Veale, until recently Registrar at Oxford University. The field covered will include the training and provision of specialist health and safety staff not only for the Authority's own purposes but to meet the needs of the nation as a whole.

Sir Alexander Fleck's health and safety committee urged the Authority last December to assume responsibility for building up the supply of specialist staff, and recruitment is in progress.

Other members of the committee include Sir Ernest Rock Carling, consultant adviser to the Ministry of Health, the AEA and the Home Office; Professor W. V. Mayneord, director of the physics department of the Institute of Cancer Research, Royal Marsden Hospital, and B. W. Windeyer, professor of Radiology (therapeutic) at the University of London.

## British reactor for Germany?

It is probable that West Germany will buy one British gas-cooled graphite-moderated reactor, according to the Federal Minister for Nuclear Energy, Professor Dr Ing Siegfried Balke, who spent five days here before returning to Germany on May 18.

During his stay he held discussions with the General Electric, English Electric and AEI-John Thompson groups and the Nuclear Power Plant Co, followed by visits to the site of Bradwell nuclear power station and the GEC atomic energy laboratories at Erith. After talks with the AEA at the Risley headquarters of the Industrial Group he went over the Springfields uranium works.

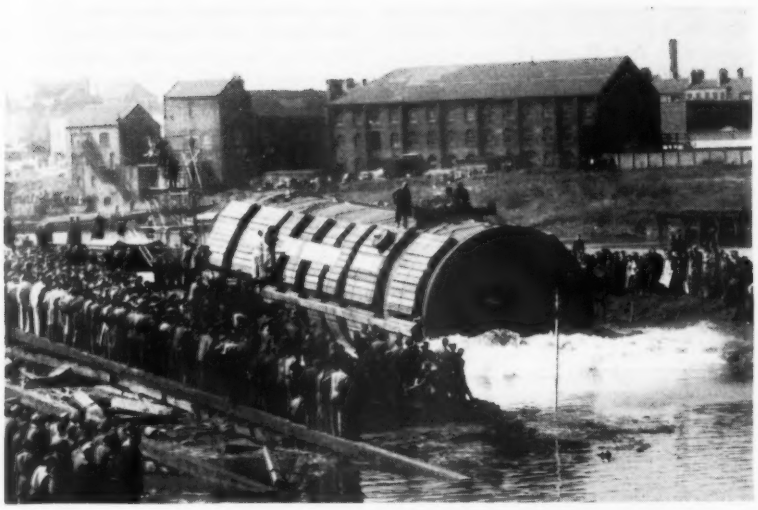
He was principally interested in comparing operating costs of Calder-type reactors with those offered by American types and discussing the possibilities of using thorium and plutonium fuel elements.

## No 1 Bradwell boiler launched

On May 16 the first heat exchanger for Bradwell nuclear power station was launched into the River Tees outside the Thornaby works of the makers, Head Wrightson & Co Ltd and towed down the North Sea to the concrete slipway at the site. The remaining eleven will be sent off at six-weekly intervals. The second, third, and fourth are in various stages of completion in the assembly and welding shops and work on the fifth has now begun.

The orthodox method of ship launching was followed, with tallow and soft soap on the slipway, and the bottom of the shell, as the heavier end, was positioned facing the river. The links were knocked away and after slight jacking it slid smoothly into the water, where two men riding on top threw hawsers to the waiting tugs.

Commenting after the ceremony on the advantages of fabricating the complete shell at the works under controlled



With thermal sleeves capped and protected by timber fenders the 200-ton shell was launched down the slipway into the Tees

conditions before transport, Sir John Wrightson, vice-chairman and managing director of the company said 'The specifications were the most stringent we have ever had to face and this contract has tested every section of our organization.' On the method of transport by sea he pointed out that road transport of all the shells would have involved blocking large sections of the Essex and East coast trunk roads and causing a periodic nuisance to road users for 22 months. The company intends gradually to increase the frequency of launchings so that the last shell should be at Bradwell in about twelve months' time.

After the first heat exchanger had been welded and stress relieved at 630°C, the thermal sleeves were capped and an air test put on the vessel to check for leaks, followed by a hydrostatic test of 270 psi. The inside was then shot blasted and the vessel sealed up in a water-tight condition. An inside coating of colloidal graphite prevented trouble from air condensation while at sea. Timber fenders were bolted into position over each bank of thermal sleeves for protection and the shell ran on rails to the head of the slipway. This was turned through 90 degrees on a steel plate turntable and jacked down to declivity onto the sliding ways.

## BELGIUM

### BR2 core on the way

The beryllium core matrices for BR2, the high flux materials and engineering test reactor under construction at Mol (Centre d'Etudes de l'Energie Nucléaire) is to be made by the US Brush Beryllium Co. The $1,200,000 contract is the largest ever placed for fabricating beryllium metal.

One of the beryllium matrices ordered from Brush will be used directly on BR2 while the other will be used in the associated core mock-up facility.

Each of the 1½ ton beryllium matrices will consist of a cluster of 64 hollow hexagonal tubes three ft long and from 3 to 8 in. dia. They will house fuel elements, control rods and test regions of the reactor core and will be connected with stainless steel extensions on top and bottom to form total fuel elements channels 30 ft long. Channel ends will be bolted to the heads of the reactor vessel. The angular array of fuel elements will converge into a compact mass at the core region, fanning out to top and bottom plate positions permitting individual access to each channel. This will normally be from the top and can be gained without removal of the pressure vessel cover. Irradiated fuel elements will be removed from the bottom directly into a canal.

## GERMANY

### Nuclear plant for sale

Britain's ability to supply a complete fuel service for power and research nuclear reactors in any part of the world was the theme of the UK Atomic Energy Authority's contribution to the British Atomic Energy stand at the Hanover Trade Fair which ended on May 6. The exhibits were closely allied to those of the Nuclear Energy Trade Association's Conference, in which models of the type of reactor which can now be bought by other countries were displayed.

This year's fair was bigger than ever, with 37,500 sq yds of floor space added to bring the total to 337,500. More than 600 of the 4320 firms exhibiting were foreign. The number of UK firms taking part rose from 48 last year to 73 making Britain third after France with 127 and Austria 95.

In 1950 only 46 foreign firms from 10 countries were represented. Now British interest is growing and many firms are convinced that the advent of the European Common Market calls for long term participation in this European shop window. The General Electric Co has made a semi-permanent booking of a stand for the next twelve years. They occupied the largest individual British electrical stand and attracted considerable attention with their new power manipulator (*Progress in Industry*, April). A female operator sitting at a small movable control console used it to pour liquids from one glass to another by remote control. Other companies which have signed a long term lease are the members of the British electronics centre display. One of the exhibits here was EMI's Emiac II computer shown solving current design problems.

As at last year's exhibition the theme of the Board of Trade sponsored display was British progress in nuclear power, though this time the main emphasis was on selling equipment and knowledge. Exhibits on the 1500 sq ft stand included models of the four nuclear stations under construction in the UK and actual examples of component parts of nuclear power stations, such as fuel elements and heat exchange tubing. Visitors were able to operate the controls of an Elliott reactor simulator, carrying out all operations from starting up to shutting down. Also on show was a model of Mullard's 4 MeV linear accelerator. One section reviewed the progress made in design since the opening of Calder Hall. Another showed how industry's capabilities in the export field range from complete power stations to the supply of instrumentation, component parts and such ancillary equipment as protective clothing. Other exhibits included a General Radiological meter for geological surveying, and equipment connected with the use of radioactivity in medical treatment and industry illustrated by an Isotope Developments' scintillation counter. A small cinema on the stand continuously exhibited a film on the principles of nuclear fission with a commentary in German.

The AEA's display gave a comprehensive account of the processes involved in producing and reprocessing the nuclear fuels used in research and in the operation of a nuclear power programme. Script, photographs, colour transparencies, models and examples of some of the actual materials used showed the stages through which uranium

Sir William Cook tries his hand at working the Elliott reactor simulator at the Hanover fair

passes from ore to fuel elements.

This year the German firms themselves indicated readiness to build nuclear plants and a model of a 200 MW reactor was on show, together with special steels and alloys.

In an article in the UK Board of Trade journal which appeared a week before the fair British industry was urged 'in its own interest to look at what is being produced on the Continent, particularly in Western Germany which next to the US is the world's biggest exporter of manufactured goods.'

## UNITED STATES

### Kept in the dark

Technology and designs developed by Kaiser engineers and Oak Ridge National Laboratory go a long way beyond the British Calder Hall work on gas-cooled reactors, at least as of Jan 1 1957, according to W. K. Davis, Director of the AEC's Reactor Development division. In his opinion present advances are probably comparable with the reactors developed for the UK CEGB except for work on fuel elements. 'In the enriched reactor' he commented 'I think we are far ahead of anyone when it comes to technology of the uranium oxide type of fuel element.'

The statement was made in response to questions by members of the subcommittee on legislation of the Congressional Joint Committee on Atomic Energy as to just how US designs of gas-cooled reactors compared with Calder Hall. William Banks of ACF Industries said that they had concluded that with metallic uranium 750°F is about the maximum temperature that can be obtained from the reactor, but by making use of a limited amount of uranium oxide upon which the US now has a fairly well developed technology a temperature of 800°F can be obtained, still using natural uranium. 'By redesigning the reactor for enriched oxide fuel and stainless steel canning we can get 1000°F gas'. Robert Charpie from Oak Ridge National Laboratory told the committee that if 1000°F gas temperature was insisted upon helium seems strongly indicated for a coolant. 'We would hope some day to do it with carbon dioxide' he added.

Subcommittee members expressed irritation over the fact that the US did not receive data from Britain as to fuel element technology although the US had shared full details on the operation of the *Nautilus*. Mr Banks testified that no information has been received on the fuel elements and US designs depended on their own resources and what they could conclude about British advances. Mr Davis pointed out that the arrangement with the UK was that the Americans were supposed to get the information on the research and development work and on Calder Hall designs up to Jan 1, 1957. 'This has been interpreted by the British to not include what they call commercial information which is the classification they put their fuel element technology under. So the only help we have got is published details'.

### Four roads to fusion

The Atomic Energy Commission has revealed details of three more thermonuclear research projects under way in addition to the PERHAPSATRON at Los Alamos, which works on the same lines as the British ZETA. Papers describing Project Sherwood — the effort to heat heavy hydrogen plasma to very high temperatures — were delivered at the spring meeting of the American Physical Society.

In one new approach a form of a magnetic bottle known as a mirror machine is being worked on by the University of California Radiation Laboratory. Ions are injected into a strong magnetic field produced by two coils round a long straight tube. At first the ions run on spirals nearly at right angles to the field. Then the current in the coils is increased and the stronger magnetic fields at the ends act as magnetic mirrors to reflect the particles of the plasma. The idea is to squeeze it in the centre region until the fusion reaction takes place.

The STELLARATOR concept being explored at Princeton University uses 'magnetic pumping' — shaking the gas with very strong alternating magnetic fields. It has been found that the resulting tendency of the plasma to drift towards the walls can be largely avoided by bending the torus into a figure-of-eight shape, but ways of 'tailoring' the magnetic field are also under study.

The work reported from Oak Ridge National Laboratory is devoted to injecting hot deuterium molecular ions directly into a plasma by means of a high voltage electrical arc. The molecular ions break down into deuterium ions (deuterons) and deuterium atoms. The atoms escape but the hot ions are caught on smaller orbits and circulate in the confining magnetic field, heating the plasma. This is not a new idea, and the whole matter hinges on efficient dissociation of the molecular ions, but good progress is claimed by using a recently developed high-vacuum high-current arc with which the molecular ions can be broken up with good efficiency. So far work on this method has been done with continuous injection into mirror coils fed with d.c. current of the type used in the University of California Radiation Laboratory.

**Short cut** Dr Jay Orear, assistant professor of physics at Columbia University has proposed using hydrogen bombs to produce electricity by developing very small ones and exploding them in semi-underground chambers containing heat exchanger pipes!

### Work started on 'Savannah'

The keel of NS *Savannah*, the world's first nuclear-powered passenger ship, was laid on May 22, National Maritime Day, in the New York Shipbuilding Corporation's yard at Camden, New Jersey.

The vessel is being constructed under the joint direction of the Maritime Administration and the Atomic Energy Commission and is due to be launched next year and make her first voyage in 1960. Besides 60 passengers she will carry about 10,000 tons of cargo. Displacing 21,000 tons the 20,000 s.h.p. ship will cost over £M15, of which the Babcock & Wilcox pressurized water reactor will account for just under £M10.

## INTERNATIONAL

### Uranium for all

The US and Canadian governments have announced that domestic producers of uranium ores and concentrates can now sell privately to buyers at home or overseas for peaceful uses. All sales will be subject to licensing by the US Atomic Energy Commission or the Canadian Atomic Energy Control Board, but it seems that permission will normally be granted for exports of any size to countries having bilaterial agreements on cooperation with the US or Canada on the peaceful uses of atomic energy. Quantities of up to 100 kg of contained normal uranium may be sold anywhere for research purposes, but no one country may receive more than 1000 kg unless it has a bilateral agreement.

The USAEC announcement said the action had been taken to permit US industry to compete for the growing foreign and domestic market for nuclear fuel. It is believed that the eighteen uranium mills now in operation and

those being built or planned would produce sufficient concentrates to meet the needs of the Commission and also to take care of growing commercial demands. Release of uranium under contract to the AEC will be considered. Possible bomb materials, i.e. plutonium, U-233 and U-235 remain on a government to government basis and cannot be sold directly to private users. Countries which have agreements with the US and can therefore receive any quantities of uranium are Australia, Belgium, Canada, West Germany, France, Italy, Netherlands, Norway, Spain, Switzerland, South Africa and the UK.

In Canada Mr Gordon Churchill, Minister of Trade and Commerce, said that private sales would be allowed if a producing mine had satisfied the government agents, Eldorado Mining and Refining, that it has uranium extra to its existing contracts. At the moment all commitments are to Eldorado which in turn has contracts with the UKAEA and USAEC.

American, Canadian and South African producers have contracts running into the 1960's, but these were made on very advantageous terms when securing uranium sources was a major worry of Western Governments. When the contracts run out it seems fairly certain that price will become a factor in influencing demand. The second of the three largest Western producers is South Africa and output is currently being discussed by the Minister of Mines and a visiting delegation from the combined development Agency representing Britain, Canada and the US.

## 200 fellowships offered to IAEA

More than 200 fellowships for advanced training abroad are now available through the International Atomic Energy Agency. Announcing this recently, Sterling Cole, director general said, 'The Agency is now in operation; this is only the beginning of a vast world-wide system of training under our aegis.' The fellowships' total value is about £350,000, and they will be financed by the Agency itself or directly by donations of member governments.

The fellowships are for terms varying between several years to a few months. They are intended to supply training in general, specialized, and research fields, and have been offered by nine countries. They are France, Italy, Japan, Poland, Rumania, the United Arab Republic, the Soviet Union, the US, and Yugoslavia. The Agency's own general fund now amounts to £21,000, of which Britain has contributed £9000, and Canada is to give £9000 this year. Since the US is matching every contribution up to a total of £45,000 this will bring the fund up to £39,000.

# WORLDBRIEFS

**Pakistan prospects** Basic limitation to the development of atomic power in East Pakistan would probably be scarcity of administrative personnel rather than capital or foreign exchange, says a report released by the US National Planning Association. It forsees little future for large nuclear power stations in either East or West Pakistan before 1957 but adds that good use might be made of small plants of 2-5 MW capacity in outlying areas which depend for power on diesel engines.

**US metal advance** An aluminium alloy which is expected to help in reducing the cost of nuclear power has been developed for fuel canning by the Argonne National laboratory. Designated X-8001 it is made by adding small amounts of nickel to aluminium 1100, a commercial alloy which contains iron, to increase corrosion resistance to high temperature water.

**Madrid exhibition** Britain was represented by exhibits covering 1000 sq ft in the International Atomic Energy Exhibition which opened in Madrid on May 10.

## Hinkley Point progress

Concreting is here taking place for foundations in the area of the first reactor. There will be five main foundations for each of the two reactors—the centre ring supporting the pressure vessels and the four abutting block foundations for the biological and supplementary shields

**Paris symposium** An international symposium on electronics in nuclear energy, organized by the Société des Radioélectriciens will be held in Paris from 16 to 20 September.

**Nuclear ships** A committee including representatives of the interests in the UK concerned with the nuclear propulsion of ships has been formed to advise the Minister of Transport and Civil Aviation on safety problems.

**Euratom** After prolonged talks between the US and Euratom over details of the proposed pact for the supply of 1000 MW of nuclear power plant by 1965 it is reported that the US has compromised on its insistance on inspection rights and in addition is offering very attractive financial terms.

**Australian isotope experiment** Design of cooling ponds for large power stations will be aided by Australia's first large scale field use of isotopes carried out on a 20 MW station. The track of radioactive iodine added to warm water fed to the pond was followed with geiger counters.

**Latin American power** Reasons given by the American and Foreign Power Co for the suspension of its programme of 3 10 MW power plants in Latin America are failure to find any insurance company which is willing to cover third party liability claims in case of accidents and its conclusion that cost of installation and operation would be much higher than original estimates.

**Cure for contamination?** The first successful use of bone marrow injections to protect human patients from the effects of large doses of radiation has been disclosed at the annual meeting of the American College of Physicians.

**Radioactive area in space** A belt of radiation 1000 times as intense as could be attributed to cosmic rays was detected by the two US Army explorer satellites. Dr James Van Allen of Iowa State University has described the layer to the American Physical Society as 'apparently stretching from about 600 miles to perhaps 8000 miles in space.' The second Soviet satellite also recorded a 'mystifying increase' in radiation.

# REACTOR TEST LOOPS

## 1. Introduction

by I. EVERSON B.Sc., A.M.I.Mech.E.

*Project Engineer, Reactor Services Group, AERE, Harwell*

*In reactor development engineering test loops are invaluable for settling fuel element design, selecting structural materials and determining other parameters under actual or simulated reactor conditions. Based on experience at Harwell, this series of four articles will include the design and operation of such loops and methods of interpreting the results.*

WHEN A NEW REACTOR of advanced design is under consideration a very large number of points arise which must be satisfactorily resolved to ensure its success. Some of the more important of these are listed below.

1. Design of fuel element, including type and disposition of fissionable material. In the case of a heterogeneous reactor, information would be required about the details of the fuel cans and the behaviour of fuel elements under irradiation. This is largely concerned with the deformation of the fissionable material and hence the containing can due to the presence of fission products, particularly the rare gases xenon and krypton, and corrosion of the can on the surfaces in contact with the coolant. The relationship between corrosion rates and fuel element can heat flux would also need investigation.
2. Criticality considerations and the best disposition of fissionable material. This is primarily the economic problem of constructing the reactor with minimum fuel investment.
3. The coolant to be employed, involving temperature pressure and velocity over the fuel element cans for a heterogeneous reactor to give the appropriate heat transfer conditions. Information would be required on the chemical stability of the coolant when subjected to neutron and gamma radiation of the levels expected in the new reactor. Data would also be required as to whether additives of any type should be introduced into the coolant to provide the necessary conditions.
4. Selection of best structural materials for coolant containment in the reactor. This should include consideration of chemical metallurgical compatability with other materials to be used in the reactor. Possible mass transfer effects should be investigated and the effect of activation and damage to structural materials due to reactor radiation is very relevant. Neutron and gamma radiation have effects on metals analogous to work hardening, often increasing hardness and strength at the expense of reduced ductility. Fast neutron bombardment is also known to raise the brittle/ductile fracture transition temperature very significantly in some metals. The annealing effect of increasing the operating temperature would also be an important point to investigate.
5. Selection of materials for critical components such as pump bearings and valve components. Compatability with materials used for other parts of the reactor and the coolant and any tendencies towards seizure would be pertinent.
6. Development of special instrumentation or selection of best commercial instruments for a particular application.

Some of this data can of course be obtained directly from previous experience or by modest extrapolation. Data not readily obtainable in this manner can best be found by experiment. Well established procedures and techniques have been developed to yield this information, the more important of which will now be described.

### In- and out-of-pile rigs

Loops can be considered as assemblies of apparatus designed to yield basic data to be used for design purposes on the main project. They can be sub-divided into out-of-pile and in-pile rigs. Out-of-pile rigs are, as their name suggests, not exposed to reactor radiation and can vary in scope from very simple apparatus to very large and complicated assemblies. They can if desired simulate coolant conditions of the proposed system. In-pile rigs are usually relatively simple in concept and serve mainly to subject small samples of constructional or fissionable materials to reactor radiation to investigate radiation damage or compatability of various materials under radiation, usually under static conditions. They do not simulate the proposed reactor coolant flow conditions.

Rigs are much in evidence in the early stages of a new

reactor project and are often used to make preliminary comparisons of numerous possible materials for a particular duty. In this way the more promising materials are selected for further investigation. They are also used for component testing for example, pumps and valves.

### Reactor test loops

These can be regarded as engineering scale experimental assemblies for use in radiation zones of research reactors to establish data subsequently used for the design of the proposed full scale reactor. Attempts are made in such loops to simulate the proposed reactor coolant conditions to make test conditions as realistic as possible.

A loop comprises a closed circuit, coolant circulator, heat source and sink, comprehensive control and safety instrumentation and any necessary ancillaries. Loops must be very carefully designed and constructed since they often operate at high temperature and high pressure and contain greater or lesser quantities of radioactivity consequent upon their exposure to reactor radiation. Severe failure of such a loop might endanger the research reactor in which it is housed or personnel in the vicinity. From the factors referred to it can be seen that a reactor test loop covers many of the problems involved, at all events in an embryo stage, in designing a full scale reactor.

### Exponential experiments

In such an experiment a sub-critical assembly is made representing a small section of the proposed reactor core. A neutron source is placed at one end of the assembly and neutron flux measurements taken at various stations. From these results, nuclear constants such as diffusion and slowing down lengths are calculated and used in the reactor core calculations. The geometry of such assemblies can be easily varied.

### Zero energy reactors

A zero energy reactor reproduces the actual reactor core and reflector geometry, complete with the full fuel investment. The design of a zero energy reactor permits changes in geometry and fuel investment to be made at will to enable the optimum arrangement to be achieved. Plots of flux distribution and the effects of various neutron absorbers can be investigated very conveniently and safely since such reactors are allowed to operate only at very low powers.

### Reactor experiment

This is a pilot scale plant and will enable the proposed reactor technology to be proved, albeit on a small scale. A reactor experiment might be limited to 10 MW whereas the full scale reactor might operate at hundreds of MW. This is the last stage before constructing a full scale reactor.

A logical sequence of events would be to make first a preliminary appraisal of materials and components by means of rig experiments, followed by reactor test loops, exponential experiments, zero energy reactor and reactor experiment leading finally to the full scale reactor. In practice such a sequence is not always adopted particularly with regard to loops. In certain circumstances it may not be worth while making reactor test loops on grounds of cost, time or envisaged usefulness of anticipated results. However it will be readily appreciated that loops play a very significant part in designing a new reactor.

While loops consist essentially of a closed circuit filled with the coolant under investigation, together with means of providing circulation, a heat source and sink, a very large number of possible variations to this basic theme can readily be evolved, of which the more important are discussed below. They can generally be considered as either coolant technology or fuel element testing loops.

### Coolant technology loops

These are intended primarily to investigate the performance of reactor coolants under conditions simulating as closely as possible those expected in the proposed reactor. Information is thus obtained on stability under radiation, the nature of any dissociation products caused by radiation, compatability of the coolant and structural materials, the effect of radiation upon corrosion rates of various structural materials in contact with the coolant and component development. The coolant temperature in such loops may be maintained by heat generated in electric

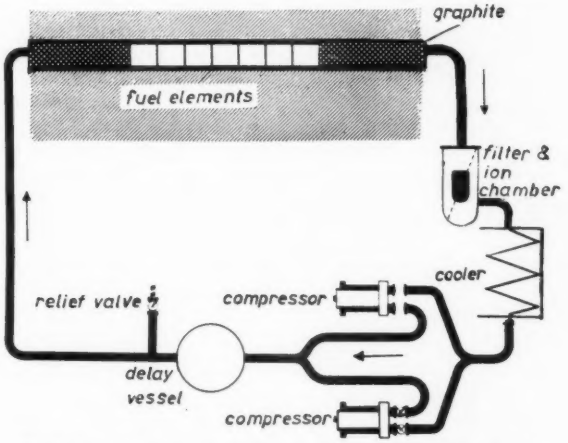



**Fig 1** A pressurized gas-cooled loop in the BEPO air-cooled reactor at Harwell was used to investigate $CO_2$/ graphite reactions. These are important for future gas-cooled systems

heaters or fuel elements containing fissionable material. The former method is used in what are referred to as 'cold' loops and the latter in 'hot' loops. In this context, 'hot' or 'cold' refers to the presence or absence of fissionable materials in the loops and has no bearing upon temperature. In 'hot' coolant technology loops it is unimportant if the fuel elements do not operate at conditions expected in the reactor under consideration. The important criterion is that coolant conditions should closely approximate to those expected in the reactor. This type of loop is extremely valuable and yields data essential to the success of the proposed reactor.

### Fuel element testing loops

This type of loop was devised essentially to test and develop fuel elements for a reactor. Fuel elements are loaded into such loops and subjected to neutron radiation from a research reactor. Information required relates to the dimensional stability of fuel elements operating at reactor conditions, the effectiveness of the method of bonding the can to the fuel, corrosion rates of canning materials and the influence of reactor radiation and the effect of ruptures in fuel element cans upon the fissionable material and coolant contamination. Fuel element testing loops are by definition 'hot' and can contain large quantities of radioactivity (upwards of 100,000 curies), mainly in the form of fission products in the fuel. Considerable attention must therefore be paid to methods for loading and unloading highly radioactive components.

There are however two serious disadvantages associated with fuel element testing loops. In the first place, fuel elements are usually housed in some sort of pressure vessel located in turn within a thimble or tube in the radiation

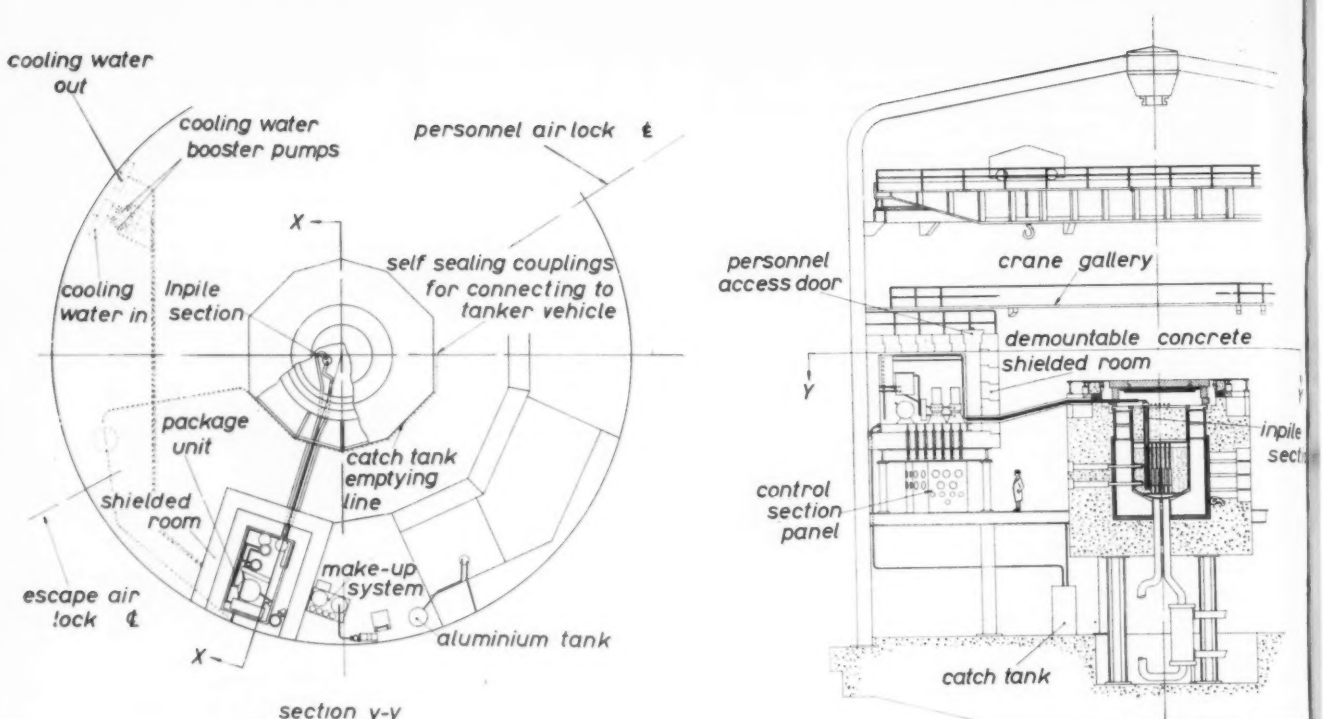



**Fig 2** This high pressure water loop installed in the DIDO heavy-water-moderated reactor is for work on pressurized water reactors. The package unit, consisting of virtually everything except the actual in-pile section is housed in a shielded room since it becomes radioactive during operation. In the case of an extreme emergency the reactor is scrammed automatically and the loop contents dumped into the catch tank

zone of a research reactor with an annular void between. It has been observed that the presence of the thimble or tube, the void, pressure vessel walls and coolant can reduce considerably the available neutron flux at the actual fuel elements themselves. This neutron flux depression can make it impossible to obtain the required heat output from the fuel elements. Thus corrosion experiments which are dependent on heat flux can lose much of their value. Furthermore the deformation of a fuel element, which is a function of the quantity of fission products formed, is dependent upon the product of heat output and radiation time. Thus if the flux depression is large, very prolonged testing may be necessary to reproduce reactor conditions so that the effect of one year's reactor operation might well require 2-3 years testing in a loop. The only effective solution to this difficulty is to carry out loop experiments in research reactors having the highest possible thermal neutron flux. Lesser improvements can of course be effected by careful design to minimize the quantities of unnecessary neutron absorbing material in the in-pile section of the loop.

Secondly, a large full scale reactor contains a very great number of fuel elements and the power output and maximum fuel element temperature is governed in part by the rate of failure of fuel cans. Since large numbers are involved we are concerned with the statistical failure rate. In any practical loop design it is not feasible to install more than a few fuel elements so that is is impossible to determine the relationship between operating conditions and statistical failure rate. These two disadvantages undoubtedly prejudice the efficacy of fuel element testing loops, particularly when the proposed reactor is designed to have a high neutron flux of the same order as available research reactors.

## Design aspects

The design of a loop is governed largely by the requirements of the reactor designer. He will specify the information the loop is required to yield and also operating parameters such as required fuel element heat output, heat flux, velocity, coolant temperature and pressure, constructional materials and methods. Upon receipt of this information the loop designer carries out a design study involving preparation of a detailed specification, flow sheet, general layout drawings, designs of critical components and nuclear considerations. These include estimates of reactivity absorbed by the in-pile section, activity and radiation shielding considerations, maximum available neutron flux inside the in-pile section and radiation damage effects.

It is often necessary to design pumps, valves and the like specially since standard commercial articles are sometimes unsatisfactory in certain respects. Special components of these categories must of course be developed adequately in rigs before incorporation into loops.

Careful attention must be paid to safety aspects of the loop under all foreseeable loop and reactor operating conditions so that it will remain safe and not endanger personnel or the reactor. For example, the case of forced coolant circulation failure must be considered. Under these conditions it is essential that the fuel element does not overheat dangerously. Sound methods must be evolved for safe handling of possibly radioactive components such as fuel elements, filters and ion exchangers. Installation of such components and removal from the loop or reactor must be easily and safely achieved. The ultimate disposal of the loop at the end of its useful life should also be considered and the design arranged to take account of this.

## Instrumentation

Adequate instrumentation must be provided to ensure correct operation under normal conditions, to detect manifestations of maloperation in good time and apply corrective measures automatically before damage can occur. Generally speaking high quality standard commercial instruments can be largely used for the more usual parameters such as temperature, pressure, flowrates, liquid level measurements, conductivity and pH. Temperature is normally measured using thermometers or thermocouples. Pressure measuring devices include bourdon type gauges and various pressure transducers. Orifice plate, electromagnetic flowmeters, venturi, pitot-static devices and rotameter type instruments are used for flowrate measurements, and sight glasses, capacitance and resistance type probes are typical liquid level measuring instruments.

However, commercial instruments are not always suitable. For example difficulty has been experienced in obtaining a commercial device for the accurate measurement and remote indication of liquid levels inside small vessels containing water operating at high temperature and pressure. One difficulty is that suitable materials for making probes for high pressure, high temperature aqueous loops have not been discovered to date. The problems involved in making a satisfactory high pressure leak tight seal with probe type instruments do not appear to have been completely solved. Differential pressure cells have been satisfactorily used for this purpose but suffer from the disadvantage that their calibration is temperature dependent. Standard recorders are often used to obtain permanent records of the more important parameters.

Special instruments are developed as required. It is necessary for instance to monitor a loop continuously to ensure that radioactivity is kept within acceptable limits. The presence of excessive radioactivity must be quickly detected and remedial action taken.

## Safety circuitry

Safe operation of loops and of the research reactor is usually catered for by arranging for loop instruments to detect automatically significant variations in the values of important operating parameters and to take the appropriate action. As an example, consider the case where electric heaters are installed to maintain the loop coolant at a predetermined temperature. The temperature under consideration could be measured by means of a thermocouple connected to a temperature recorder fitted with two microswitches. Should the temperature rise, one microswitch will interrupt the electrical supply to the heater and conversely, when the temperature falls, the second microswitch will re-energize the heaters. If appropriate, additional microswitches can be installed within the recorder to give an alarm if a high temperature occurs and if a very high temperature is detected additional coolant circulators or cooling devices could be actuated.

In this way comprehensive circuitry can be devised to ensure safety of the loop, research reactor and personnel. It is customary for three degrees of safety actions to be specified. For small variations from required values of important parameters, a warning is given, both audible and visual, while for larger variations remedial actions are made on the loop—for example heaters and pressurizing devices can be rendered inoperative. In the event of serious malfunctioning severe damage could result. The reactor is then tripped and if necessary it may be arranged that the contents of the loop are dumped into a special container.

It is customary to connect thermocouples intended for reactor trip action to individual trip amplifiers which have no moving parts as it has been found that this is the most reliable method for such devices. High and low pressure trips are actuated by pressure switches. Other parameters required to trip the reactor are considered separately and the appropriate instrument selected.

The circuitry is designed to fail safe so that failure of a component or power supply will initiate a safety action.

## Construction and testing

Constructional materials are carefully selected and for critical components bonded material is used, manufactured to high standards and to rigorous inspection requirements. Inspection certificates cover all manufacturing stages of this material. The best manufacturing techniques are devised, backed up by rigorous inspection. For example welding is widely used in loops and it is customary to require welders to undergo tests to establish their competence using the materials and methods peculiar to each loop. Non-destructive inspection techniques are widely employed to ensure the requisite standard of workmanship. These include radiography (both X and gamma), ultrasonic and magnetic flow detection equipment and penetrant dye surface crack testing. Special components such as valves and pumps are often developed separately to the required standard of reliability before installation in a loop.

On completion of the loop, comprehensive tests are made at the place of manufacture to satisfy all concerned that the specification has been complied with. These tests often require some weeks to complete, particularly when modifications become necessary prior to the reactor design team accepting the loop as satisfactory.

## Installation and commissioning

A new loop, having been tested at its place of manufacture, will then be transported to the research reactor building. All out-of-pile equipment will first be installed. The in-pile section would be suitably housed out-of-pile and connected temporarily to permanent out-of-pile equipment. Further additional out-of-pile tests will then be carried out and modifications made as necessary to achieve the desired degree of reliability. All instruments and safety circuitry will be finally adjusted and alarms and trips set and at this stage loop safety circuitry is integrated with that of the reactor.

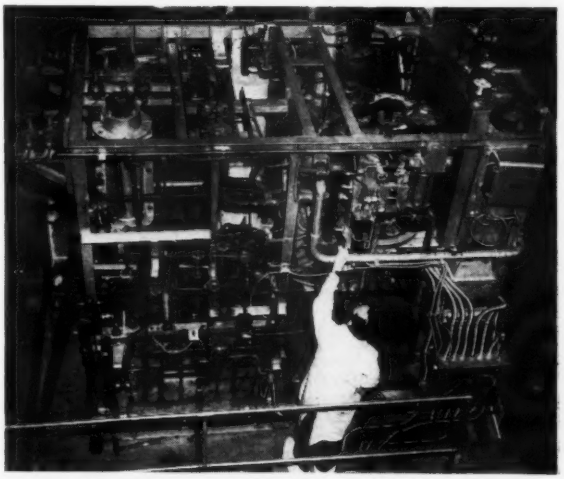


**Fig 3** Floor space round DIDO is at a premium and so the h.p. water package unit is designed to a high degree of compactness. It includes pumps, heaters, coolers, ion-exchange columns and filters and is fully instrumented for remote control

All features associated with in-pile operation must be simulated during these final tests. For example, procedures

for loading and unloading fuel elements, using any special precautions such as fuel element cooling during unloading, must be properly rehearsed. Replacement of components liable to become radioactive in service, such as filters, must be practised using special operational equipment. The latter might include heavily shielded flasks.

Concurrently with these final out-of-pile tests, detailed operating and descriptive manuals would be prepared in addition to reports on special features of the loop which may become apparent at this time. A vital object at this stage is to train and familiarize loop operators and users with all phases of the loop and how to use it to the best advantage.

On successful completion of out-of-pile test, the in-pile section is loaded into the reactor. Initially the in-pile loop is operated 'cold,' i.e. while the coolant operates at the specified temperature and pressure, no fissionable material is loaded into it. This gives opportunity for final checks and adjustments before beginning 'hot' operation. Fissionable material in the appropriate form is fed into the loop. This can take the form of solid fuel elements for a heterogeneous system or a solution of fissionable material in its coolant if a homogeneous system is being investigated. The loop is then ready to go into service.

## Operation and maintenance

In the initial stages of its useful life it is essential to bring all operating instructions and data up to date. All operations must be carried out with the utmost care, in accordance with written instructions. Methodical operation is essential to achieve the best results with safety. Routine inspection and maintenance must be carried out during reactor shut-down periods, which will occur at regular intervals. All alarms, trips and safety circuitry should be tested wherever circumstances permit. Regular reports should be issued describing tests carried out and listing in detail all defects and faults arising in the period in question.

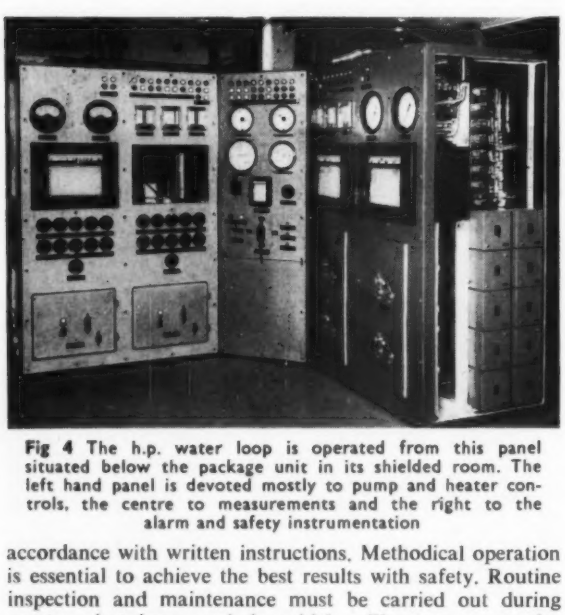


**Fig 4** The h.p. water loop is operated from this panel situated below the package unit in its shielded room. The left hand panel is devoted mostly to pump and heater controls, the centre to measurements and the right to the alarm and safety instrumentation

At the end of its useful life it will be necessary to remove the loop from the reactor and to dismantle it. This operation must be carefully planned well in advance and every effort made to recover as many components as possible. Some of these may need decontamination to reduce radioactivity to safe levels. It is highly probable that the in-pile section at least will be scrapped. This is usually done in a special building designed to handle highly radioactive equipment. This process should be carried out carefully so as to obtain as much useful information as possible in so doing. Activity can be measured to provide correlation with other data, the nature of deposits will be of interest to scientists, the mechanical properties of the coolant container will give information about radiation damage, metallurgical investigations can be made and so on.

## Organization for design

In view of the complex problems involved such as space, safety, reactor and neutron economy a special organization has been set up at Harwell to design, install, commission and operate all reactor test loops.

The team investigating a new reactor, the so-called loop users, initiates a reactor test loop as the best means of obtaining certain information. The users next approach the loop design group for an engineer to act as loop designer and give him sufficient information to make a preliminary design study. A formal proposal to construct a loop, together with the results of the preliminary design study, are then submitted to an independent committee for approval. This committee is composed of specialists in the chemistry, physics, metallurgy, engineering, and electronics of reactors and is concerned primarily with safety considerations relating to the loop, research reactor and personnel.

On receipt of this first stage approval by this committee, a detailed design study is made, specifications and key drawings prepared. Permission is sought to use the appropriate reactor experimental hole. The committee is then approached for second stage approval. At this stage detailed consideration is given to possible operational hazards to equipment and personnel. All points raised by the committee must be cleared before it grants second stage approval.

Detailed design and manufacture can then take place. The loop is finally installed in the reactor building and subjected to intensive out-of-pile testing. At this stage various documents are prepared. These include a descriptive report, detailed operating manual, reports on health physics aspects and special features of the loop and a detailed commissioning report listing all faults encountered and remedial action taken.

When the loop designer considers the loop ready for in-pile operation he approaches the committee for third and final stage approval. The committee critically appraises the loop and when all its criticisms have been satisfactorily dealt with, third stage approval is given and the loop can then be installed in the reactor and operations begun. At this stage the loop designer transfers responsibility for the loop to the operating engineer.

The loop is maintained under periodic review during its working life. Its utilization is considered by the research reactor operating committee regularly when coordinating all experimental work being carried out in a given research reactor to achieve best overall results. Regular reports are then issued by the operating engineer and the necessary information fed back to the reactor design team. Planned inspection and maintenance ensures prolonged safe operation of the loop during its working life.

As mentioned earlier, a very wide range of possible loop designs exist. Some of these are illustrated by the following examples.

## Pressurized gas-cooled pile loop

This loop was evolved to assist in designing carbon dioxide-cooled piles. It is illustrated diagrammatically in figure 1 and consists of a closed circuit constructed largely of stainless steel filled with $CO_2$, with duplicate $CO_2$ circulators. The in-pile section occupies a fuel element channel in the BEPO pile and contains a number of annular

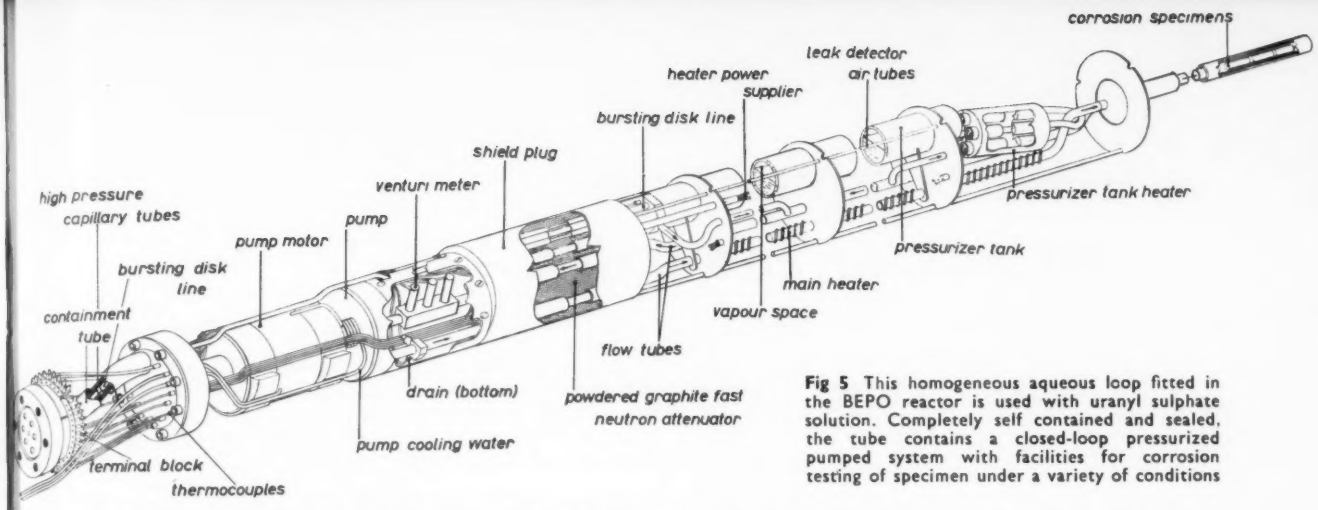



**Fig 5** This homogeneous aqueous loop fitted in the BEPO reactor is used with uranyl sulphate solution. Completely self contained and sealed, the tube contains a closed-loop pressurized pumped system with facilities for corrosion testing of specimen under a variety of conditions

graphite sleeves with fuel elements housed inside them. Means are provided for monitoring the $CO_2$ activity to give indication that one or more fuel elements had ruptured, thus releasing fission products into the $CO_2$ stream.

Comprehensive instrumentation was incorporated for control and safety purposes. The loop was evolved primarily to investigate the possible chemical reaction between $CO_2$ and graphite moderator under simulated reactor operating conditions of temperature and irradiation in a gas-cooled pile. The graphite sleeves contained samples of known weight which were checked before and after an experiment. Fuel elements were included to provide the correct radiation conditions and temperature gradients in the experimental channel. No heat transfer experiments were made in the loop which may therefore be regarded as a coolant technology loop.

## High pressure water loop

This was evolved to give information for the design of pressurized water reactors, particularly for marine propulsion purposes. Information was required regarding optimum water conditions, since high and low pH give high corrosion rates, maintenance of water conditions, dissociation of high pressure and temperature water due to radiation, corrosion rates of several likely structural materials and fuel element testing. Thus this loop can be regarded as fulfilling the functions of both coolant technology and fuel element testing. It was decided to install this loop in the high flux research reactor DIDO. Figure 2 illustrates the general installation of this loop relative to the reactor. This loop consists essentially of a closed circuit mainly of mild steel with two stainless steel pumps for circulating high pressure and temperature water. Fuel elements will be housed in a steel pressure vessel mounted in a vertical thimble, the lower end of which is subjected to intense reactor radiation. Provision is made for taking water samples from the loop, since analysis of these gives valuable information regarding water conditions and corrosion rates.

With a loop of this type the out-of-pile equipment is bulky, and for convenience as much of it as possible is mounted within a massive steel framework, referred to as the package unit. This is illustrated in figure 3. Because the loop water becomes radioactive during its passage through the in-pile section, heavy shielding is required around the package unit and pipes connecting it with the in-pile section. To this end the package unit is contained within a concrete room with 2 ft thick walls. It is, of course, necessary to control numerous valves from outside the shielded room during operation. These valves are therefore provided with extended spindles with operating handwheels located beneath the shielded room. All important instruments and switchgear are mounted on a special panel housed beneath the shielded room, as shown in figure 4. Water sample points are concentrated within a steel Perspex structure referred to a drybox. Apparatus for introducing chemicals into the loop is also located in the drybox. Comprehensive instrumentation is provided for automatic control of the loop and for safety purposes. Provision is made for tripping the loop heaters and pumps in case of malfunctioning and under extreme conditions the reactor will be tripped and the loop contents dumped into a special tank. Special devices were designed for safe handling of fuel elements and other radioactive components. A loop of this magnitude might take 2 years between the original conception and starting useful operation and then have a useful life of 2 to 3 years.

## Homogeneous aqueous loop

This loop was designed to yield information for the design of the homogeneous aqueous reactor. In this reactor the fissionable material, uranyl sulphate, is dissolved in water, thus no fuel elements are involved as for heterogeneous reactors. Consequently, this loop can be regarded as a coolant technology loop and intended to give information regarding solution stability, optimum operating conditions, compatibility of structural materials, comparative corrosion tests of various materials and component development with special reference to pumps and valves. The loop consists of a closed stainless steel circuit filled with uranyl sulphate solution provided with a special pump to circulate the solution. Corrosion specimens are loaded before the loop is finally welded up. Means are provided for pressurizing the loop and adding gases as required. Because of the high specific coolant activity, special attention was paid to containment and leak detection. The pump and primary circuit are totally enclosed within an aluminium thimble sufficiently strong to withstand the effect of a serious rupture of the high pressure circuit. Normally circulation occurs only in this part of the loop which is illustrated in figure 5 and is virtually a sealed unit housed in a horizontal experimental bore in BEPO. The only solution lines emerging from this unit are small bore capillary tubes leading to sampling and gas addition units. All of these are carefully contained to prevent leakage into the surrounding area. In addition, electrical and instrument lines emerge from the otherwise sealed unit. Comprehensive instrumentation is provided for control and safety purposes including loop and pile trips.

The in-pile section containing the primary circuit and pump is regarded as expendable and is dismembered after each experiment lasting some three months. Much information and data can only be obtained in this manner by then inspecting various critical parts of the loop. Special devices were made to facilitate unloading the highly active in-pile section after testing. Out-of-pile equipment will, of course, be used for a number of in-pile sections during the useful two-year life of the loop.

# Heat extraction in power reactors—1

*by G. BOXER, Ph.D.*

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*In this, the first of a special series of four articles, Dr Boxer outlines the fundamental theories of heat transfer by conduction and convection. In the remaining three of the series, these theories will be applied to power reactors. Radiation heat transfer is not included because it is only of secondary importance in this context. A knowledge of the basic reactor physics is assumed throughout.*

BEARING IN MIND the long history of man's dependence on fossil fuels such as coal and oil for the production of power, the advent of nuclear power can be considered even now as a comparatively recent occurrence. The essential difference between the coal or oil fired power plant and a nuclear power plant is the manner in which heat energy is first produced. The burning of coal with air to produce heat energy for the production of steam from water in a boiler is readily understood. However, the mode of heat production in a nuclear reactor is determined by the manner in which the nuclei of fissionable material, such as uranium 235, are split by neutrons of a given energy level. The subsequent release of energy due to fission in uranium 235 will manifest itself as heat and can be used to produce steam in a heat exchanger external to the main reactor.

Figure 1 shows a simplified diagrammatic layout of a heterogeneous, thermal reactor system in which the primary coolant is carried round a closed circuit which is pressurized and exchanges its heat with the secondary water/steam circuit in the external heat exchanger. A study of this figure indicates that the logical steps in applying fundamental heat transfer theory to this system are as follows:

1. thermal conduction of heat energy through the fuel elements and sheathing to the sheath surface
2. heat transfer into the primary coolant stream flowing past the fuel elements by convection
3. the effect of axial conduction of heat along the reactor coolant channel
4. the estimation of pressure drops along the coolant channels as determined by coolant mass flow, coolant properties and resulting temperature differences set up. This leads to a determination of the pumping power required for the primary coolant.

In addition it is appropriate to discuss the relevant properties required by a suitable reactor primary coolant.

To formulate the basic equations governing the distribution of temperature in the fuel elements, sheathing and primary coolant, it is convenient to give a brief recapitulation of the relevant fundamental laws of heat transfer.

## Three modes of heat transfer

Heat energy can be transported in three ways:

1. by conduction in which for example the molecules of a gas undergo elastic impacts with resultant changes of energy
2. by convection in which the heat energy is carried bodily by transfer of mass

There are two forms of convective heat transfer:

a. natural or free convection in which the formation of temperature differences in a medium give rise to buoyant forces due to density differences and a resultant energy movement
b. forced convection in which energy is transported by macroscopic fluid motion due to the action of some external agency such as a pump or fan.

3. radiation in which attention is focused on that form of

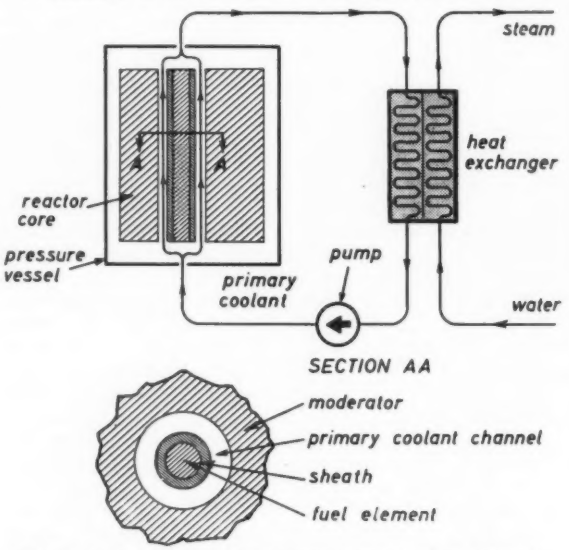


**Fig 1** Coolant flow through one channel of a thermal, heterogeneous reactor

energy transportation through a permeable medium due to temperature-excited, electro-magnetic waves.

The basic difficulty in the analysis of most systems in which a transfer of heat is involved is that all three modes occur simultaneously and rigorous mathematical treatment is often impossible. In certain clearly defined cases, however, separate modes do exist and individual mathematical treatment is then

possible. It is possible, also, to superpose laws where more than one mode exist together, in certain other instances.

The remainder of this section is devoted to a recapitulation of the laws of steady flow heat transfer by conduction and convection since these are the two important modes in nuclear power reactors.

## Steady flow heat conduction

In this elementary treatment we shall be concerned mainly with the estimation of steady state temperature distributions in the reactor fuel elements and sheaths and in the reactor coolant. The effect of temperature 'excursions' due to changes in reactor power are not treated here.

The basic law of heat conduction originates from the work of the French physicists Biot and Fourier and can be stated as

$$Q = \frac{kA\Delta T}{x} \qquad (1)$$

Where $Q$ = heat flow in unit time in the direction of decreasing temperature
$A$ = area of medium normal to heat flow
$\Delta T$ = temperature difference causing heat flow
$x$ = distance between two planes in the medium between which there is a temperature difference $\Delta T$
$k$ = thermal conductivity of the medium which is the factor of proportionality in the above equation.

The full Fourier equation may be derived by considering a

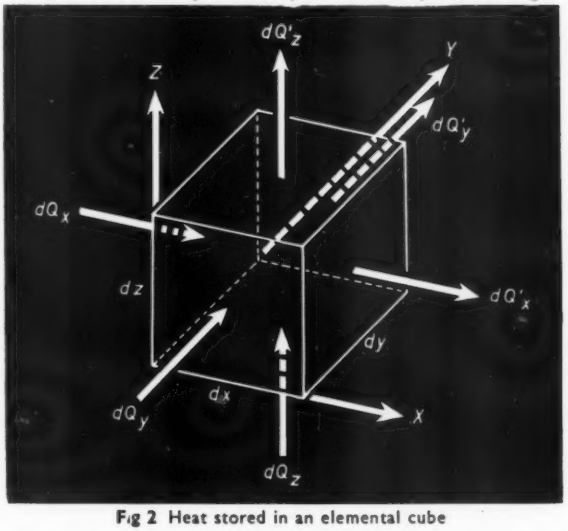


Fig 2 Heat stored in an elemental cube

cube of sides $dx$, $dy$ and $dz$ (figure 2) in the three-dimensional Cartesian system.

Let $dQ_x$, $dQ_y$ and $dQ_z$ be the rates of flow of heat into the cube in the $x$, $y$, and $z$ directions respectively,

while $dQ^1x$, $dQ^1y$ and $dQ^1z$ are the rates of heat flow out of the cube in $x$, $y$, and $z$ directions respectively.

Expressing equation (1) in differential form we may say

$$Q = -kA\frac{dT}{dx} \qquad (2)$$

Thus in the $x$ direction

$$dQ_x = -k\frac{\partial T}{\partial x}\,dy\,dz \text{ entering the cube}$$

and $$dQ^1x = dQ_x + \frac{\partial}{\partial x}(dQ_x)\,dx \text{ leaving the cube}$$

or $$dQ^1x = -k\left[\frac{\partial T}{\partial x} + \frac{\partial^2 T}{\partial x^2}dx\right]dy\,dz \text{ leaving}$$

Thus the net flow in the $x$ direction is given by

$$dQ_x - dQ^1x = -k\frac{\partial^2 T}{\partial x^2}\,dx\,dy\,dz$$

and the net flows in the $y$ and $z$ directions are given respectively by

$$dQ_y - dQ^1y = -k\frac{\partial^2 T}{\partial y^2}\,dx\,dy\,dz$$

and $$dQ_z - dQ^1z = -k\frac{\partial^2 T}{\partial z^2}\,dx\,dy\,dz$$

If we now specify that

$H$ = heat generated in the cube per unit volume per unit time
$\rho$ = density of medium
$C_p$ = specific heat at constant pressure of medium

we may formulate a balance of energy between the heat flowing into and out of the cube, the heat generated in the cube and the heat stored in the cube.

Thus $$\rho C_p\frac{\partial T}{\partial t}\,dx\,dy\,dz =$$

$$H\,dx\,dy\,dz + k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right]dx\,dy\,dz \qquad (3)$$

or $$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] + \frac{H}{\rho C_p} \qquad (4)$$

where $\rho Cp$ = volumetric heat capacity,

and $\frac{k}{\rho C_p}$ = thermal diffusivity.

Note that in general $H = F(x, y, z \text{ and } t)$ and that in steady flow $\rho C_p\frac{\partial T}{\partial t} = 0$.

This result may also be expressed in cylindrical polar coordinates as follows:

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\left[\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2}\right] + \frac{H}{\rho C_p} \qquad (5)$$

Equations (4) and (5) are generally intractable, except in certain practical cases where simplifying assumptions may be introduced quite legitimately.

The application of equations (4) and (5) will now be considered in three elementary cases where simplifying assumptions make possible a direct mathematical solution. They are:

1. steady heat conduction through a plane plate of uniform conductivity
2. steady heat conduction through a hollow cylinder of uniform conductivity
3. steady heat conduction through a hollow sphere of uniform conductivity.

In all three cases, the variation in thermal conductivity is ignored and $H$ and $\frac{\partial T}{\partial t}$ are assumed to be zero. That is the heat sources or sinks causing heat flow by conduction are assumed to be situated at the boundaries of the body and

* A full list of symbols used is given on page 271

there are no sources or sinks inside the bodies considered.

**1. Infinitely wide plane plate or plate of finite width, perfectly insulated at the edges**

Heat flow is assumed to occur in the $x$ direction only. Thus in equation (4) $\frac{\partial T}{\partial t} = H = \frac{\partial^2 T}{\partial y^2} = \frac{\partial^2 T}{\partial z^2} = 0$

$$\text{Thus } \frac{d^2T}{dx^2} = 0 \tag{6}$$

Equation (6) may be integrated directly and its solution is $T = Dx + E$ where

$D$ and $E$ are the two arbitrary constants of integration determined by introducing the relevant boundary conditions.

Suppose the boundary conditions to be such that:

$T = T_1$ at $x = x_1$ and $T = T_2$ at $x = x_2$

$$\text{Thus } D = \frac{T_1 - T_2}{x_1 - x_2} \text{ and } E = \frac{T_2x_1 - T_1x_2}{x_1 - x_2}$$

$$\text{or } T = \left[\frac{T_1 - T_2}{x_1 - x_2}\right] x + \left[\frac{T_2x_1 - T_1x_2}{x_1 - x_2}\right] \tag{7}$$

also from equations (1) and (7)

$$Q = -kA\left[\frac{T_1 - T_2}{x_1 - x_2}\right] \tag{8}$$

$$\text{or } q = -k\left[\frac{T_1 - T_2}{x_1 - x_2}\right] \tag{9}$$

**2. Infinitely long hollow cylinder or cylinder of finite length with the ends perfectly insulated**

With reference to figure 3 and applying equation (1) to steady, radial conduction through a cylindrical shell of radius $r$ and thickness $dr$,

$$Q = -k\ A\ 2\pi r \frac{dT}{dr} \tag{10}$$

Integrating equation (10) between $r_1$ and $r_2$ for a length $L$ of cylinder,

$$Q = \frac{-kL\ 2\pi\ (T_1 - T_2)}{\ln r_1 - \ln r_2} \tag{11}$$

$$\text{or } Q = \frac{kL\ 2\pi r_m\ (T_1 - T_2)}{r_2 - r_1} \tag{12}$$

$$\text{where } r_m = \frac{r_2 - r_1}{\ln r_2/r_1} \tag{13}$$

and $r_m$ is called the logarithmic mean radius.

Also integrating equation (10) between $r$ and $r_2$

$$Q = \frac{-kL\ 2\pi\ (T - T_2)}{\ln r - \ln r_2} \tag{14}$$

and from equations (11) and (14)

$$T = \left[\frac{T_1 - T_2}{\ln r_1 - \ln r_2}\right] \ln r + \left[\frac{T_2 \ln r_1 - T_1 \ln r_2}{\ln r_1 - \ln r_2}\right] \tag{15}$$

Equation (15) may be derived alternatively by the use of cylindrical polar coordinates as follows:

Considering in figure 2 a shell of inner radius $r$ and outer radius $r + dr$.

The heat flow into the shell $Q_i = -kL\ 2\pi r \frac{dT}{dr}$ (from equation (1)), and the heat flow out of the shell $Q_o =$

$$-kL\ 2\pi\ (r+dr)\left[\frac{dT}{dr} + \frac{d\ (dT)}{dr\ (dr)}\ dr\right],$$

$$\text{or } Q_o = -kL\ 2\pi\ (r+dr)\left[\frac{dT}{dr} + \frac{d^2T}{dr^2}\ dr\right]$$

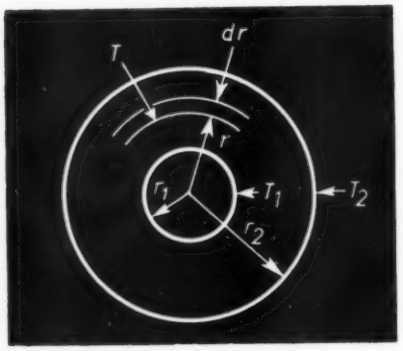


**Fig 3** Radial convection through a hollow cylinder or sphere

With the same assumptions as before we may write:

$Q_i = Q_o$ or

$$0 = -kL2\pi r \frac{d^2T}{dr^2} dr - kL2\pi \frac{dT}{dr} dr - kL2\pi dr \frac{d^2T}{dr^2} dr$$

and neglecting $(dr)^2$ compared with $dr$,

$$\frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr} = 0 \tag{16}$$

The solution of this equation can be carried out by substituting a new variable $P = \frac{dT}{dr}$ and rewriting equation (16) in the form

$$\frac{dP}{dr} + \frac{P}{r} = 0$$

which after separating the variables and integrating gives the solution,

$$P = \frac{C_1}{r}$$

where $C_1$ is the first constant of integration for equation (16).

Substituting back for $P$ we may say

$\frac{dT}{dr} = \frac{C_1}{r}$, or integrating a second time,

$$T = C_1 \ln r + C_2 \tag{17}$$

where $C_2$ is the second constant of integration of equation (16).

Substituting the original boundary conditions into (17) i.e.

$T = T_1$ at $r = r_1$ and $T = T_2$ at $r = r_2$,

we derive equation (15) again.

**3. Steady, radial conduction through hollow sphere**

With reference to figure 3 again, which will serve this analysis equally well, we can write for a spherical shell of radius $r$ and thickness $dr$ from equation (2) applied to radial flow of heat,

$$Q = -k\ A \frac{dT}{dr} = -k\ 4\pi r^2 \frac{dT}{dr}, \tag{18}$$

and integrating this equation between $r_1$ and $r_2$

$$Q = \frac{k\ 4\pi\ (T_1 - T_2)}{\frac{1}{r_1} - \frac{1}{r_2}} \tag{19}$$

Also integrating from $r$ to $r_2$ we may say,

$$Q = \frac{k\,4\pi\,(T - T_2)}{\frac{1}{r} - \frac{1}{r_2}} \qquad (20)$$

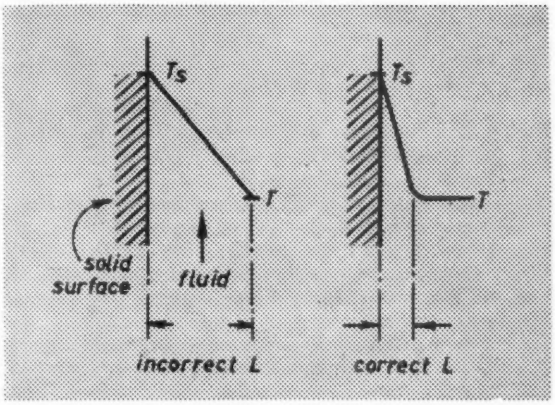


**Fig 4** Temperature gradient through the boundary layer in convection from a solid surface—correct and incorrect illustration

Equating (19) and (20)

$$T = \left[\frac{T_1 - T_2}{\frac{1}{r_1} - \frac{1}{r_2}}\right]\frac{1}{r} + \frac{\left[\frac{1}{r_2}T_2 - \frac{1}{r_1}T_1\right]}{\left[\frac{1}{r_1} - \frac{1}{r_2}\right]} \qquad (21)$$

Alternatively in spherical polar coordinates we may say

$$Q_1 = -k\,4\pi\,r^2\frac{dT}{dr},$$

$$\text{and } Q_0 = -k\,4\pi\,(r + dr)^2\left[\frac{dT}{dr} + \frac{d^2T}{dr^2}dr\right]$$

and stipulating the same conditions as before

$$Q_1 = Q_0 \text{ or}$$

$$Q_1 - Q_0 \quad 0 = -k4\pi r^2\frac{d^2T}{dr^2}dr - k8\pi r\,dr\frac{dT}{dr} - k8\pi r\,dr\frac{d^2T}{dr^2}dr$$

$$-k4\pi(dr)^2\frac{dT}{dr} - k4\pi(dr)^3\frac{d^2T}{dr^2}dr$$

Neglecting $(dr)^2$ and $(dr)^3$ compared with $dr$,

$$\frac{d^2T}{dr^2} + \frac{2dT}{r\,dr} = 0 \qquad (22)$$

The solution of equation (22) may be effected in a similar manner to that described for equation (16) and the result is

$$T = -\frac{C_3}{r} + C_4 \qquad (23)$$

and on substituting the given boundary conditions we arrive at equation (21) again.

The above three examples serve to show the method of approach to all steady flow conduction problems and the results expressed in differential form by equations (6), (16) and (22) will be of use when the effect of internal heat generation is considered in the fuel elements.

## Convection

The basic equation for all convective heat transfer is given by Newton's law of cooling, namely:

$$Q = h\,A\,(T_s - T) = h\,A\,\Delta T \qquad (24)$$

where $Q$ = heat flow per unit time through an area $A$ of the surface of a solid to a fluid flowing past the surface (say)
$T_s$ = surface temperature of solid
$T$ = bulk mean fluid temperature.

This apparently simple equation is rendered intractable in most practical cases because of two major difficulties:

a. $h$, which is known as the local coefficient of heat transfer from solid to liquid (or vice versa), is not a constant but depends on several factors including the system geometry, rate of fluid flow and the properties of the fluid.
b. accurate estimation of $T$ is extremely difficult if not impossible.

Rewriting equation (24) in the form

$$Q = \frac{k_f}{L}A\,\Delta T \qquad (25)$$

where $k_f$ = thermal conductivity of the fluid
and $L$ = thickness of the fluid layer in contact with the solid surface over which there is a linear change of temperature,

we may say that an accurate estimation of $k_f$ is possible but further difficulties arise in the estimation of $L$. Figure 4 shows both a correct and an incorrect illustration of the distribution of temperature in the fluid layer adjacent to the solid surface.

Bearing these difficulties in mind, it is understandable that most convective heat transfer problems resolve at once into the estimation of an accurate value of $h$. Thus general information on a given value of $h$ to cover a widely different

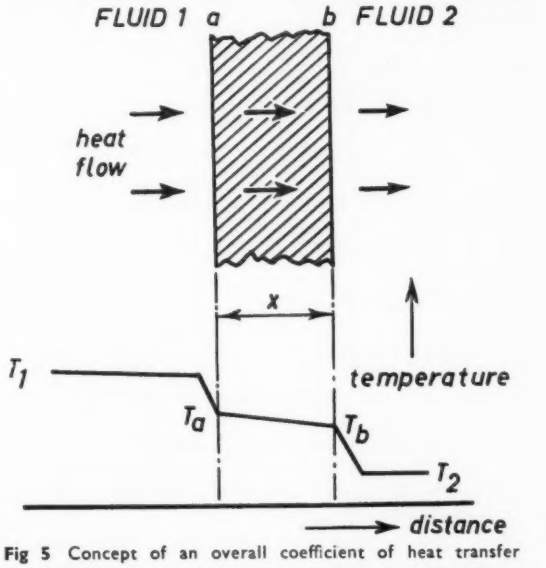


**Fig 5** Concept of an overall coefficient of heat transfer

array of systems is not forthcoming. Tedious and numerous experiments are often necessary to furnish evidence for the adoption of a suitable value of $h$.

In certain instances the analysis of equation (24) is partly resolved by the use of dimensional reasoning, a brief outline of which appears later.

## Solids and fluids in series

As defined in equation (24), $h$ is known as a local coefficient of heat transfer. The concept of an overall coefficient of heat transfer at once becomes feasible when analysing the transfer of heat through a series of fluids and solids adjacent to each other.

For simplicity consider in figure 5 flow of heat in one direction by convection from fluid 1 to surface *a* of solid *ab*, by conduction through *ab* and by convection from surface *b* to fluid 2.

Let $h_{1a}$ be the local coefficient of heat transfer from fluid 1 to surface *a*,

$h_{b_2}$ be the local coefficient of heat transfer from surface *b* to fluid 2,

$k_{ab}$ be the thermal conductivity of the solid *ab*.

$$\text{Then } Q = h_{1a} A (T_1 - T_a) = \frac{k_{ab} A (T_a - T_b)}{x} = h_{b_2} A (T_b - T_2)$$

$$= U A (T_1 - T_2)$$

where $U$ is an overall coefficient of heat transfer relating conditions directly between the two fluids 1 and 2.

Thus on this basis

$$\frac{1}{U} = \frac{1}{h_{1a}} + \frac{x}{k_{ab}} + \frac{1}{h_{b_2}}$$

$$\text{Or in general } \frac{1}{U} = \Sigma \frac{1}{h} + \Sigma \frac{x}{k} \qquad (26)$$

## Forced convection

This is the most predominant form of convective heat transfer since the low flow rates necessary for natural convection do not occur very often in practice.

With reference to figure 6, considering the flow of hot fluid

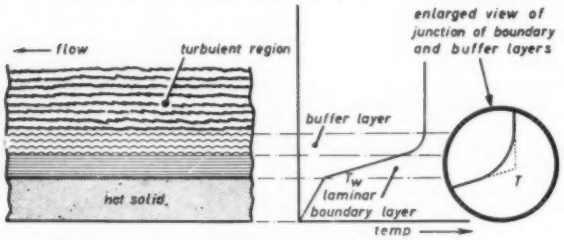


**Fig 6** Temperature distribution from a solid surface to a cold fluid

past a cold solid surface, there will be three distinct regions of fluid adjacent to the surface.

1. the viscous or laminar boundary layer, in which the flow is wholly parallel to the surface. The temperature gradient through this layer is steep and is created by the transfer of heat from the fluid to the solid surface by thermal conduction
2. the buffer layer separating the laminar and turbulent regions in which the temperature distribution is given by the curve in figure 6. An approximation to this curve is normally adopted as shown by the dotted line
3. the fully turbulent region in which the fluid has its highest temperature and heat is transferred by forced convection.

With the approximation for the buffer layer as shown we may assume that the combined thickness of the laminar and buffer layers is $\delta$, say, and we may then write

$$Q = \frac{k_f A (T_w - T)}{\delta} \qquad (27)$$

where $T$ = temperature at the junction of the laminar and turbulent layers on $XX$,

$T_w$ = wall surface temperature on $XX$,

$k_f$ = thermal conductivity of fluid,

$$\text{or } Q = h A (T_w - T) \qquad (28)$$

The above argument is reasonably correct for all fluids for which the Prandtl number is not greater than 2. This embraces most liquids and gases.

## Principle of similarity in convection

It is possible to use the results of a small number of experiments to furnish information on the value of $h$ for a wide range of application by using the principle of similarity.

Certain generalizations may be formed about the patterns of heat flow and fluid flow from a consideration of the full differential equations governing forced convection heat transfer.

If two systems of fluid flow around solid bodies (for example) are to be dynamically or physically similar the following conditions must be satisfied:

1. the bodies and system boundaries must be geometrically similar
2. the distribution of fluid velocity around the systems must be similar in magnitude
3. the distribution of temperature across the boundaries of the system must be similar in magnitude.

Provided that 1, 2 and 3 are satisfied it can be shown that:

4. the velocity distributions within the boundaries are similar when the Reynolds numbers are the same for both systems
5. the temperature distributions within the boundaries are similar when the Prandtl numbers are the same for both
6. If 4 and 5 are satisfied, then the Nusselt numbers will be the same for corresponding elements of the solid surface, and thus the average Nusselt number will be the same for both solid surfaces.

The definition of the Reynolds, Prandtl and Nusselt numbers will be made clear from the following discussion on dimensional reasoning.

## Dimensional reasoning applied to convection

We can derive, by dimensional reasoning, the manner in which $h$ depends on the relevant parameters in convection at least in a general sense as shown below. A consideration of the mechanism of convection with turbulent flow shows that the relevant parameters can be expressed in the most general way as

$$F_1[Q, A, v, \Delta T, D, \mu, \rho, C_p, k] = 0 \qquad (29)$$

where $Q$ = heat flow in unit time

$A$ = surface area for convective heat transfer

$v$ = bulk mean fluid velocity

$\Delta T$ = temperature difference between solid surface and bulk of the fluid

$D$ = characteristic linear dimension of the system

$\mu$ = fluid viscosity

$\rho$ = fluid density

$C_p$ = specific heat of fluid

$k$ = thermal conductivity of fluid.

Rewriting equation (29) we may say:

$$\frac{Q}{A \Delta T} = h = F_2[v, D, \rho, \mu, C_p, k] \qquad (30)$$

This result can be expressed as a series of products of powers of the parameters involved so that

$$h = v^a D^b \mu^c \rho^d C_p^e, k^f \qquad (31)$$

We may in addition stipulate that the five main dimensions are as follows:

$H$—unit of heat flow

$M$—unit of mass

$L$—unit of length

$t$—unit of time

$T$—unit of temperature.

Substituting these dimensions into equation (31) we have

$$\frac{H}{L^2 T t} = \left[\frac{L}{t}\right]^a L^b \left[\frac{M}{L t}\right]^c \left[\frac{M}{L^3}\right]^d \left[\frac{H}{M T}\right]^e \left[\frac{H}{L T t}\right]^f \qquad (32)$$

Thus equating exponents in the above equation we have for $H$ $\quad 1 = e + f \qquad (33)$

$$\text{for } L \quad -2 = a+b-c-3d-f \tag{34}$$
$$\text{for } M \quad 0 = c+d-e \tag{35}$$
$$\text{for } T \quad -1 = -e-f \tag{36}$$
$$\text{for } t \quad -1 = -a-f-c \tag{37}$$

Now equations (33) and (36) are identical leaving four equations for six unknowns. It is convenient in this case to express $a$, $b$, $c$ and $e$ in terms of $d$ and $f$.

Thus in (36) $e = 1-f$

in (35) $c = e - d = 1 - f - d$

in (37) $a = 1 - f - c = 1 - f - 1 + f + d = d$

in (34) $b = f - 2 + c - a + 3d = f - 2 + 1 - f - d + 3d - d = d - 1$

Thus substituting back in equation (32)

$$h = v^d D^{d-1} \mu^{1-f-d} \rho^p C_p^{1-f} k^f$$

$$\text{or } h = \left[\frac{v D \rho}{\mu}\right]^d \left[\frac{\mu C_p}{k}\right]^{1-f} \frac{k}{D} \tag{38}$$

$$\text{or } \frac{h D}{k} = \left[\frac{v D \rho}{\mu}\right]^d \left[\frac{\mu C_p}{k}\right]^{1-f} \tag{39}$$

$$\text{or } N_u = F_3(R_e, P_r) \tag{40}$$

where $N_u$ the Nusselt number, is a dimensionless form of the coefficient of heat transfer $h$, and

Reynolds No. $R_e$ is a dimensionless flow parameter determined by the geometry of the system and flow rate, and

Prandtl No. $P_r$ is a dimensionless number depending on the intrinsic fluid properties.

The above reasoning has been developed for forced convection and the following is a summary of the corresponding results for natural or free convection.

$$N_u = F_4(G_r, P_r) \tag{41}$$

where the Grashof number $G_r$ is defined as

$$G_r = \frac{\rho^2 D^3 \Delta T \beta g}{\mu^2} \text{ where}$$

$\beta$ = the coefficient of thermal expansion of the fluid,
$g$ = the gravitational constant and
all other parameters are as defined as for forced convection.

Thus the Grashof number plays a corresponding role in free convection to that played by the Reynolds number in forced convection.

In most practical cases free and forced convection occur simultaneously and the most general relationship would be expressed as follows:

$$N_u = F_5(R_e, G_r, P_r) \tag{42}$$

One other dimensionless group is of value in this application, namely $S_t$, the Stanton number which may be defined as

$$S_t = \frac{h}{\rho v C_p}$$

The physical significance of this group is best shown by considering a heat balance between the heat transferred by forced convection from the fuel sheath surface to the heat taken up by the coolant in the channel surrounding the fuel element. With reference to figure 1 let

$M$ = mass flow of coolant in a channel
$T_1$ = temperature of coolant at channel entry
$T_2$ = temperature of coolant at channel exit
$T_s$ = sheath surface temperature
$T_m$ = bulk mean coolant temperature
$Q$ = rate of addition of heat to coolant per unit time
$C_p$ = specific heat of coolant at constant pressure
$\rho$ = coolant density
$v$ = bulk mean coolant velocity
$A$ = coolant channel cross-sectional area
$S$ = sheath surface area for convective heat transfer.

Thus drawing up simple heat balance we may say:

$$Q = M C_p (T_2 - T_1) = \rho A v C_p (T_2 - T_1) = h S (T_s - T_m)$$

$$\text{or } S_t = \frac{h}{\rho v C_p} = \frac{A}{S} \frac{(T_2 - T_1)}{(T_s - T_m)} \tag{43}$$

Equation (43) demonstrates that the Stanton number is the product of two ratios: firstly the ratio of channel area to sheath surface area and secondly coolant temperature rise to mean temperature difference between sheath surface and bulk mean coolant temperature.

In addition we can show that

$$\frac{N_u}{(R_e)(P_r)} = \frac{h D}{k} \frac{\mu}{v D \rho} \frac{k}{\mu C_p}$$

$$\text{or } \frac{N_u}{(R_e)(P_r)} = \frac{h}{\rho v C_p} = S_t \tag{44}$$

Thus from equations (40) and (44) it follows that

$$S_t = F_5(R_e, P_r) \tag{45}$$

The above digression on dimensional analysis has served merely to define and explain briefly the physical meaning of four dimensionless groups which are of direct value to the material of the succeeding three articles in this series.

A discussion on the effects of fluid friction is left over to the second article where it fits into the general framework most suitably.

It will be clear that the statements made here on the fundamental theory of conductive and convective heat transfer have been abbreviated due to space limitations. In order that the reader may pursue any particular topic in more detail a suitable reading list is appended.

**References**


Jakob, M. *Heat Transfer*, 1st ed Vol 1, 1949, Wiley, New York.
A full mathematical treatment of conduction will be found in this book. In addition a fuller treatment of the principles underlying dimensional similarity will be found in chapter 23.

Boelter, L. M. K., Cherry, V. H., Johnson, H. A., and Martinelli, R. C. *Heat Transfer Notes*, 1948, University of California Press, Berkeley and Los Angeles.
A rigorous treatment of dimensional analysis is given in chapter XI.


## NOMENCLATURE

$Q$ = heat flow per unit time
$q$ = heat flux per unit time $= \frac{Q}{A}$
$A$ = area for heat transfer
$T$ = temperature
$t$ = time unit
$L$ = length unit
$M$ = mass unit
$C_p$ = specific heat at constant pressure
$\rho$ = density
$\mu$ = viscosity
$k$ = thermal conductivity
$H$ = unit of heat and heat generated per unit volume of material per unit time
$r$ = polar coordinate – radius
$\theta$ = polar coordinate – angle
$h$ = local coefficient of heat transfer
$U$ = overall coefficient of heat transfer
$\delta$ = boundary layer thickness
$v$ = bulk mean fluid velocity
$D$ = characteristic linear dimension of system

**Dimensionless groups**

$N_u$ = Nusselt number $= \frac{h D}{k}$
$R_e$ = Reynolds number $= \frac{v D \rho}{\mu}$
$P_r$ = Prandtl number $= \frac{C_p \mu}{k}$
$S_t$ = Stanton number $= \frac{h}{\rho v C_p}$
$G_r$ = Grashof number $= \frac{\rho^2 D^3 \Delta T \beta g}{\mu^2}$

French research workers at Saclay

are pioneering a new approach

to the problem of joining nuclear metals

# Vacuum welding by electron beam

*by J.-A. STOHR*

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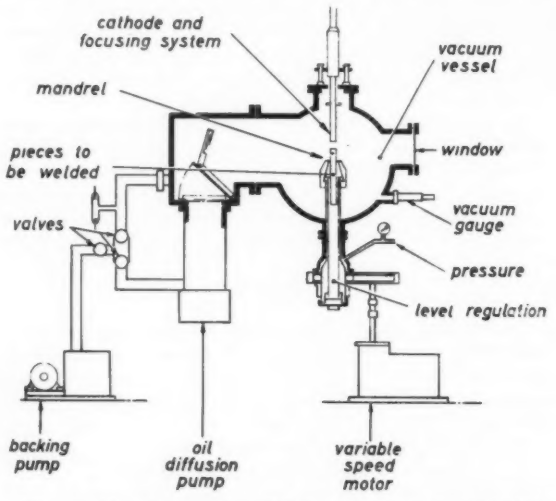
EVEN WITH PROCESSES such as argon-arc, fusion welding of certain metals can be done only at the risk of altering their properties. In the case of zirconium, for example, to obtain satisfactory results it has been necessary to develop special controlled atmosphere chambers which can be filled with argon or helium (one of these was described in NUCLEAR POWER last month, p 219). These have to be loaded, completely evacuated and then filled with high purity gas before welding can be started and then special arrangements have to be made to maintain the gas purity and prevent contamination of the inside of the chamber by water vapour. Most of these problems could be overcome if it were possible to weld in a vacuum.

## Electron heating

The only practical heat source for use in a vacuum is electron bombardment and this has already been used in other applications such as fusion furnaces, microscope stage-plate heating and zone refining. Means of producing, accelerating and focusing electrons are well known and it is easy to produce a strongly focused beam on a very small target area. The energy dissipated on the surface is proportional to the number of electrons striking it in unit time and their kinetic energy—in other words to the beam current density and the acceleration potential. If the target is moved along a line corresponding to the edges of the two pieces to be joined it is possible to melt the metal and so obtain a continuous fusion weld under vacuum.

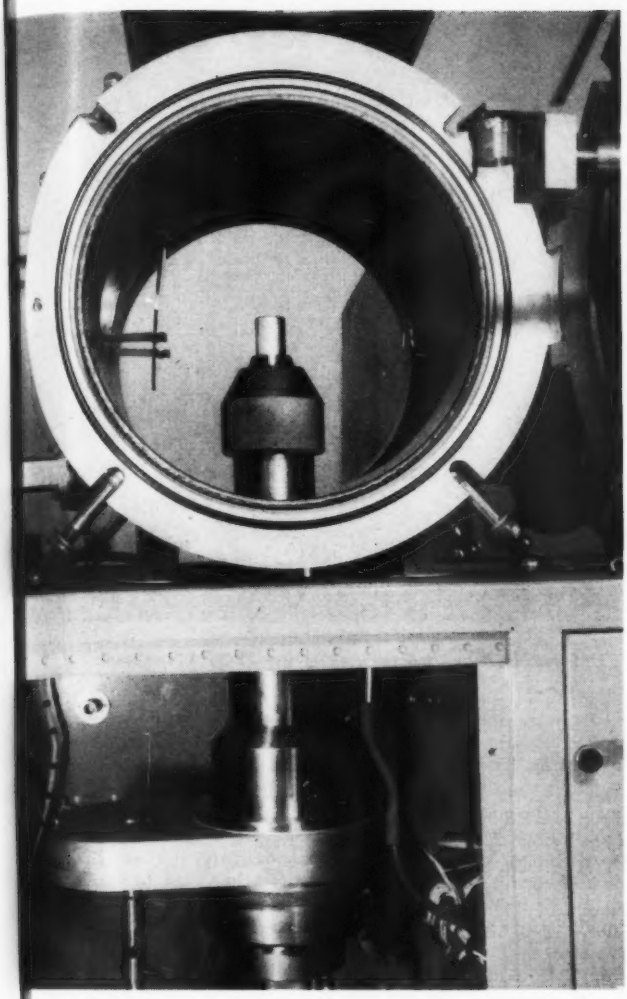
The unit power, in watts per square centimeter, which can be obtained in this way is considerable, and a variety of different kinds of weld is possible. In very thin materials, target areas of 0·1 sq mm can be obtained without difficulty and thus a precision can be achieved which is quite unobtainable with shielded-arc methods. Furthermore, the fact that the weld is made in vacuo excludes all risk of oxidization or other contamination. In thicker metals with target areas of between 6 and 8 sq mm, it is possible to dissipate as much as 50 kW. With the refractory metals such as tungsten, molybdenum and tantalum, or the reactive ones like zirconium, beryllium or uranium, results obtained by this method have been remarkable.

The power which can be dissipated on the surface depends on the energy of the electrons, i.e. on the potential difference between the electrodes, and this can be maintained




The machine for canning EL3 fuel elements incorporates the essential features of the system. An improved machine carries a magazine of 30 cartridges and another is designed for linear welds

only if the space between them does not become ionized. This would lead to electrical breakdown and can occur as a result of electron collisions with metal atoms vaporized from the surface. For a given geometry the amount of ionization depends on the metal and on the size of



Close-up of the chamber of the fuel element machine shows how the can is rotated in a chuck below the electron gun

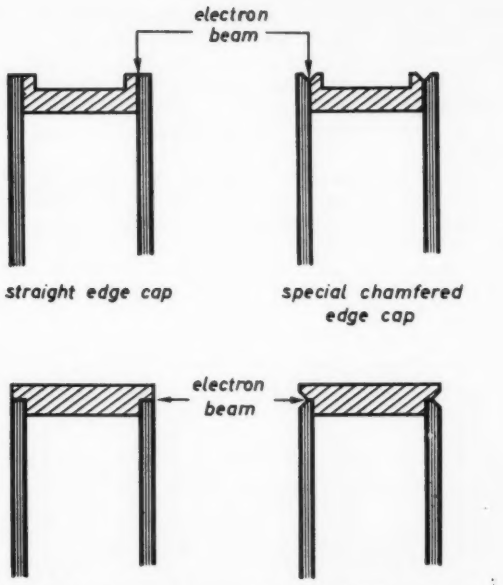
the target area, the following table giving the mass of metal vaporized per second from unit area at the melting temperature.

| metal | Q g/cm²/s | temp °C |
|---|---|---|
| aluminium | $<10^{-8}$ | 660 |
| zirconium | $2 \times 10^{-6}$ | 1750 |
| tantalum | $1{\cdot}4$ to $1{\cdot}3 \times 10^{-5}$ | 2996 |
| tungsten | $1{\cdot}4 \times 10^{-4}$ | 3382 |
| beryllium | $4{\cdot}4 \times 10^{-5}$ | 1280 |
| magnesium | $>10^{-3}$ | 650 |

The quantity $QS$ ($S$ being the area of the target) is proportional to the number of metal atoms per cubic centimetre and represents the probability of ionization in the path of the electron beam. It is highest close to the surface of the metal.

### Preventing arcing

In the case of metals which vaporize easily, such as magnesium, ionization would quickly lead to electrical breakdown and arcing across the electrodes, so it is necessary to weld intermittently by chopping the beam current. If the speed of the workpiece through the beam is correctly related to the frequency of beam chopping, the weld will consist of a series of overlapping spots.

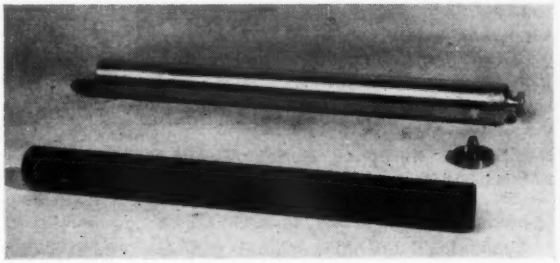


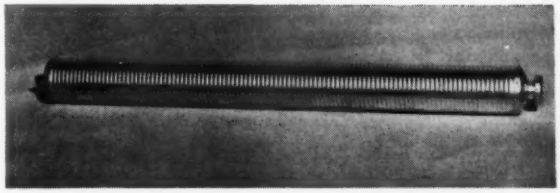

Fuel can closures may be made in several different ways—with the electron beam parallel or perpendicular to the axis, with or without edge preparation

At Saclay an electronic beam welding machine has been built for circular welds such as are used in making tube closures. It consists of a horizontal cylindrical stainless steel chamber with observation ports, connected to a high vacuum system. This comprises an oil-diffusion pump with an output of 900 litres/sec down to $10^{-4}$ mm and a backing pump with an output sufficient at the priming pressure of the diffusion pump to ensure its correct operation. A roughing pump with an output of 90 cu m/h rapidly brings the pressure in the chamber down to $10^{-1}$ mm. A valve system for changing over from the roughing pump to the high vacuum pump and the usual gauges complete the system.

The tungsten filament electron gun projects into the chamber at the top and has both fine and coarse posi-

Stages in the canning of the EL3 element show the plain can and end-cap, the threaded bar and the complete vacuum-sealed cartridge with the can pressed into the threads

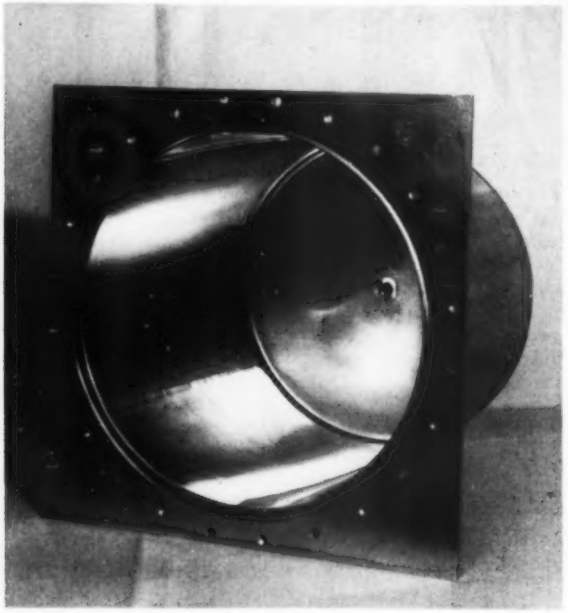




tional adjustments, the former being operable only when the chamber is open. The workpiece, positioned directly below the gun, is rotated in a mandrel or chuck driven by a thyratron-controlled, variable-speed motor and the whole assembly can be raised or lowered inside the chamber by another motor driving through a rack-and-pinion gear.

High voltage supplies to the cathode come from a high tension rectifier fed from a 3-phase mains transformer. Although the cathode voltage is controllable up to 60 kV, voltages of between 10 and 14 kV are normally used in welding. Both electrostatic and electromagnetic focusing have been used, but the latter has been found to be more flexible.

The primary current is interrupted by a thyratron-controlled chopper which gives the overlapping spot welds already mentioned. This system gives a greater penetration of the metal, avoids collapse of the sides of the weld due



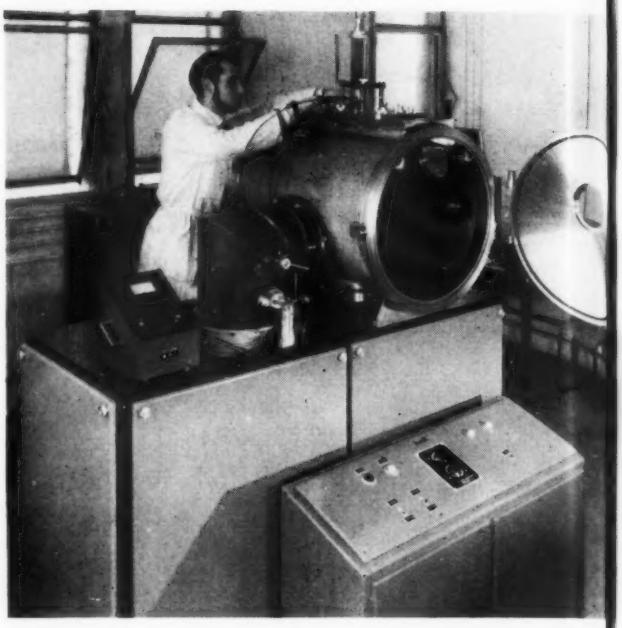
This small zirconium tank for the Saclay homogeneous reactor PROSERPINE was welded entirely electronically

to metal flow, and of course allows the welding of strongly vaporizing metals.

In any metal this also permits a greater area of melting but it is however only possible if the ratio $\frac{\text{weld time + off time}}{\text{weld time}}$ is small, and this necessitates moving the workpiece very slowly in order to obtain sufficient overlap.

## Canning of fuel elements

A modification of this apparatus has been used at Saclay for canning fuel rods for the high-flux research reactor EL3. In this element the uranium bar has a helical groove machined along its entire length and it is inserted into a plain aluminium can already closed at one end. The cartridge is now fitted into the mandrel with the open end in the chamber which is then pumped down to about $10^{-5}$ mm. The end piece is then placed in position by remote manipulation and the weld made by electron beam in the way described. The complete cartridge is now hot-pressed by hydrostatic pressure so that the walls of the can sink

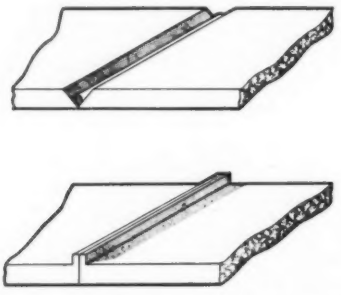


This machine was used for making the PROSERPINE tank. It can do both linear and circular welds

into the groove in the bar. Heating can be done without risk of oxidization since of course there is already a vacuum in the can left from the welding operation. This method of evacuating and sealing in one operation has already lowered the cost of the elements.

A drawback of this particular machine is that only one cartridge can be closed before it is necessary to break the vacuum and an improved machine is being built to speed up the process. This is generally similar but it includes a rotary magazine containing 30 cartridges which can all be sealed during one evacuation.

Instead of rotating the workpiece, it can of course be moved linearly by quite a simple mechanism so that seam welds can be done. At Saclay a machine adapted for both linear and rotational welds was used for fabricating



Welds may be made using V-groove edge preparation and filler rod or by special raised edges. In some cases no preparation is needed at all

the small zirconium tank for the homogeneous reactor PROSERPINE. With this system, welds may be made in thick materials using edge preparation and filler rod in the form of wire which is laid along the groove. With thin sheet no edge preparation is required.

This article is based on one which appeared in *Bulletin d'Informations Scientifiques et Techniques*, March 1958, with permission of the Commissariat à L'Energie Atomique. This has been supplemented with additional information supplied by M Stohr.

# D.C. AMPLIFIERS FOR REACTOR INSTRUMENTATION

*by M. W. JERVIS, M.Sc.(Tech), A.M.I.E.E.*
*AEI-John Thompson Nuclear Energy Co Ltd*

*Relatively large operating forces are needed to actuate indicators, recorders and relays measuring and controlling reactor parameters such as neutron flux and temperature. Some form of d.c. amplifier is necessary and this article describes the various types available.*

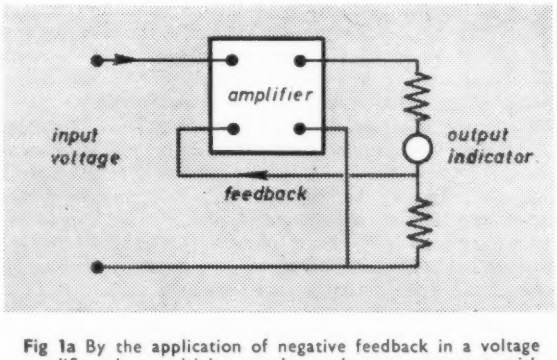



**Fig 1a** By the application of negative feedback in a voltage amplifier the sensitivity can be made more constant with respect to time and voltage fluctuations

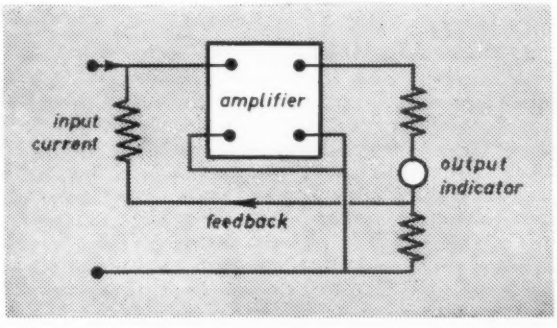



**Fig 1b** In current measurements, determined from the voltage drop across a resistor, the feedback is applied to the earthy end of the input resistor, reducing the effect of leakage to earth

## 1.1 General

TWO IMPORTANT QUANTITIES which require accurate measurement for the safe and efficient control of nuclear reactors are temperature and neutron flux. These quantities are converted to electrical signals, usually by thermocouples and ionization chambers. Although in principle the output of these devices can be measured by the classical instruments such as reflecting galvanometers and quadrant electrometers, these are obviously unsuitable for installation in power stations. Such an application necessitates the display of information on large, easily read indicators or its recording on large pen recorders or electrical typewriters. In addition to display or recording, it is often necessary for the measured variable to operate an alarm or safety circuit if it goes outside its normal operating limits in either an upward or downward direction.

Large indicators, recorders and relays in alarm circuits imply relatively large operating forces and it is necessary to interpose some form of d.c. power amplifier between the detector and the display equipment or alarm and safety system.

## 1.2 Classification

D.c. amplifiers can be conveniently classified according to their input impedance. For example, an amplifier for use with a chromel-alumel thermocouple of resistance 100 ohm operating at 500°C might have a full scale output for an input of 25 mV and an input resistance of 10,000 ohm and would be classified as a low impedance amplifier.

Low impedance amplifiers can be described as voltage amplifiers, while high impedance amplifiers are also used as current amplifiers. In this case the current is measured in terms of the voltage drop, as given by the amplifier, across a known resistor. For this application the input resistance of the amplifier must be high compared with the measuring resistor. For example, a low level neutron ionization chamber might have an input current of $10^{-11}$

amp when the reactor is shut down. Such a current could be measured by a 10 volt input d.c. amplifier and $10^{12}$ ohm resistor.

### 1.3 Negative feedback

In some cases, which will be discussed later, a non-linear relationship between input and output is required. This is exceptional, however, and in most cases a linear characteristic is desirable with the output accurately proportional to the input. It is also important that the sensitivity of the amplifier should be constant with time and with variations in the supply voltage. Another desirable property is that the input resistance should be large compared with the resistance of the source of voltage being measured. Furthermore, the response time should be reasonably short, a typical figure being in the region of 1 second.

The extent to which these conditions can be satisfied is greatly increased by the application of negative feedback, the arrangement for a voltage amplifier being illustrated in figure 1a. A fraction of the output is fed back to the input in a sense which opposes the input signal. This reduces the sensitivity of the complete amplifier but in return for this, the sensitivity can be made more constant with respect to time and supply voltage fluctuations. Negative feedback can also be arranged to give a reduction in response time and reduces the loading of the amplifier input on the source being measured.

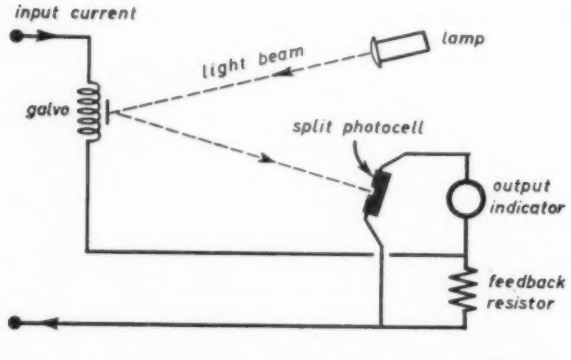



**Fig 2** In the galvanometer amplifier, the input voltage or current is applied to a reflecting galvanometer and the light spot arranged to activate a split photocell: in this case a photo-voltaic type

When measuring current, the d.c. amplifier is used to measure the voltage drop across a resistor through which the input current is passed. In this case the feedback is applied to the earthy end of the input resistor (figure 1b). This has the effect of keeping the input lead near earth potential so that the effect of leakage to earth is reduced.

## 2. LOW IMPEDANCE AMPLIFIERS

### 2.1 Galvanometer amplifiers

One of the earliest forms of d.c. amplifier is the galvanometer amplifier. In this arrangement the voltage or current to be measured is applied to a reflecting type galvanometer. The light spot is made to fall on a photo-cell instead of a scale and the output of the photo-cell then operates an indicator (*1*). The photo-cell is usually split and may be of the photo-voltaic type (figure 2) or the photo-emission type followed by a thermionic amplifier. In their simplest form these arrangements give a non-linear characteristic and are sensitive to mains voltage fluctuations affecting the light intensity. By the application of negative feedback, however, satisfactory performances can be obtained. One version of the galvanometer amplifier uses a gas-filled triode amplifier and has been designed for industrial applications (*2*).

Other methods of detecting movement of the galvanometer coil are possible. In one instrument the coil carries a metal flag near the inductor of a valve oscillator, the anode current of which is altered by the position of the flag. Another system uses two coils, one of which rotates in an a.c. field. The voltage induced in this coil depends upon the position of the coil.

### 2.2 Modulators

As will be shown later, direct coupled valve amplifiers are not suitable for low voltage measurement because of their zero drift. By converting the d.c. input into an alternating voltage, the source of drift is moved from the valve to the d.c. to a.c. conversion device. It is found that these modulators can be designed to give much less voltage drift than valves.

Two types of modulators which are in common use as the d.c. to a.c. modulator at low impedance levels are the magnetic and the contact modulator.

#### 2.2.1 Magnetic amplifiers

Many types of magnetic amplifier have been described, but the most satisfactory for low level work is known as the second harmonic type of modulator (*1*). A magnetic core is fitted with three windings, an excitation winding providing sufficient ampere turns to drive the core well into saturation, an input signal winding and an output winding. In the absence of any signal, the voltage from the output winding will be symmetrical with respect to time. A current in the input winding destroys the symmetry so that the output voltage contains a second harmonic component. By using two cores connected 'back to back,' the fundamental frequency components can be made to cancel while the second harmonic components add. The modulators are then followed by suitable amplification and the output is finally rectified back to d.c. Negative feedback is used to linearize the system and raise the input resistance.

It can be seen that the galvanometer and the magnetic amplifiers both use coils of wire and that the sensitivity is a function of the number of ampere turns. Since the number of turns is fixed by the winding space available and the smallest usable gauge of wire, the maximum current sensitivity is limited. These instruments must therefore be classified as low impedance devices suitable for measuring voltages from such sources as thermocouples. Recently, magnetic amplifiers have been used in combination with thermionic input stages. Thus a high input resistance is obtained, the magnetic amplifier being used to provide the output power.

#### 2.2.2 Contact modulator amplifiers

Among the various methods which have been employed for d.c. to a.c. conversion, the contact modu'ator probably has the widest application. The arrangement is shown in figure 3, an interruptor being used to 'chop' the steady input into a square wave which can be amplified by an a.c. amplifier. The amplifier is usually tuned to remove harmonics and reduce the effects of noise originating within it. This amplifier is followed by a phase sensitive detector which may take the form of a diode circuit or contacts synchronized with the input modulator. D.c. negative feedback is applied from output to input.

If the amplifier is to be used for amplifying voltages from low impedance sources, a step-up transformer can be used between chopper and amplifier input. This gives a voltage step-up without introducing any significant noise

## AMPLIFIER UNITS

| FIRM | SCALE | TYPE | INPUT VOLTAGE OR CURRENT RANGE | INPUT STABILITY | ACCURACY | OUTPUT VOLTAGE OR CURRENT | OUTPUT INDICATION AND TRIP FACILITIES | OTHER NOTES |
|---|---|---|---|---|---|---|---|---|
| **Airmec Ltd.**<br>*High Wycombe, Bucks.* | linear | N855 chopper | mV level | $< \pm 50$ mV in 4 hours | linearity $\pm 2$ pc. f.s.d. | 0-30V,8-0·3mA | max. 80 mV at 3k Ω load | input impedance 4M Ω |
| **Avo Ltd.**<br>*Avocet House, London, S.W.1* | linear | 1388B valve | $10^{-6}-10^{-12}$ f.s.d. at 10V<br>$3\times10^{-7}-3\times10^{-13}$ f.s.d. at 3V | <25mV variation over several weeks | $\pm 3$ pc. f.s.d. | 100mV for recorder operation | meter | for calibrating ionization chambers |
| **Ekco Electronics Ltd.**<br>*Southend-on-Sea* | period and log current | RPM 1513B valve | $5\times10^{-12}-5\times10^{-5}$ amp. | 1 pc. | $\pm 10$ pc. | 100 mV across 100 Ω for f.s.d. | current and period meters 2 CO or 4B contacts | fail-safe, tropicalized cf. RPM 1389B |
| | linear, sliding-range | SNSM 1399A valve | $5\times10^{-9}-5\times10^{-10}$ amp. | 0·5 pc. | $\pm 10$ pc. | | direct reading in m rem/hr. 0–150 & 0–15 | portable, fast response |
| **Elliott Bros. (London) Ltd.**<br>*Century Works, London, S.E.13* | linear | RP valve | 5 ranges $10^{-7}-10^{-11}$ f.s.d. | $< \pm 0{\cdot}5$ pc. | approx. 2 pc. | 5V | meter, recorder output 10mV no trips | deviation amplifier normally used after linear scale |
| | backed-off linear | mechanical chopper | | 100 μV | 1 pc. | 5V | meter, recorder output | remote changing may be provided |
| | log | valve & magnetic | $10^{-12}-10^{-7}$ amp. | 2½ pc. f.s.d./3 days | 2 pc. f.s.d. | 2·5V | meter, recorder output 10mV f.s.d.; trip preset $10^{-11}$ amp. | |
| **Electromethods Ltd.**<br>*Caxton Way, Stevenage, Herts.* | linear, backed-off linear | magnetic | ε. $1\times10^{-6}$ watts | long term $3\times10^{-11}$ watts | <1 pc. | up to 20mA into 120 Ω, 50mA sat. | output meter or relay | up to 20 independent signal windings available. Power gains up to 20,000 |
| **Electronic Instruments Ltd.**<br>*Richmond, Surrey.* | linear | B33C valve | $10^{-15}-10^{-9}$ amp. | $\pm 100$mV/12 hrs. | $\pm 1$ pc. | 1mA into 1500 Ω | meter | |
| **Ericsson Telephones Ltd.**<br>*Beeston, Nottingham* | linear | 129A self-rectifying chopper | 50, 5, 0·5 and 0·05 μA f.s.d. | ε. 1 pc. f.s.d. on 0·05 μA, otherwise 0·1 pc. f.s.d. | | 15V f.s.d. | 100mV signal for pot. recorder | fail-safe circuit |
| **General Radiological Ltd.**<br>*Great Portland Street, London, W.1* | log | RPM NE035 valve | $5\times10^{-11}-5\times10^{-5}$ amp. | calibration stab. $\pm 0{\cdot}5$ pc. | calibration acc. $< \pm 10$ pc. | | meter, f.s.d. 1mA pot. recorder 100mV f.s.d. Trip $10^{-11}-10^{-5}$ amp. | cf. RPM NE039 input current $10^{-13}-10^{-6}$ amp. |
| **Integra, Leeds & Northrup Ltd.**<br>*Edgbaston House, Birmingham 15* | linear | 9836 vibrator | 6 ranges $10^{-8}$ to $5\times10^{-4}$ amp. f.s.d. | | for source resistance 0·1 to >1 MΩ 0·5–0·8 pc. reading $\pm 2\times10^{-11}$amp. | | meter, recorder outputs | |
| **Isotope Developments Ltd.**<br>*Aldermaston Wharf, Reading* | linear | 1656 valve | $10^{-12}-10^{-4}$ amp. | $< \pm 1$ pc. f.s.d. /24 hrs. | $\pm 2$ pc. f.s.d. | 100mV across 120 Ω | meter | input impedance $10^{8}$ Ω on most sensitive range |
| **Labgear Ltd.**<br>*Willow Place, Cambridge* | log | 1453B valve | $10^{-8}-10^{-11}$ amp. | | $\pm 15$ pc. | 0–1mA across 100 Ω | 270° meter, preset alarm | provision for external recorder (100mV) |
| **Plessey Nucleonics Ltd.**<br>*Weedon Road, Northampton* | linear | PN1037 valve | 0 to +3 or −3V<br>0 to +10 or −10V<br>$10^{-13}$ to $10^{-5}$ amp. | $< \pm 3$ pc. long term | $\pm 3$ pc. | | moving coil meter | |
| | log | PN1036 valve | $10^{-13}-10^{-6}$ amp. | | $\pm 10$ pc. | | moving coil meter 2 CO contacts | trip circuit adjustable over 6 decades of meter scale range |
| **W. G. Pye & Co. Ltd.**<br>*Newmarket Road, Cambridge* | linear | 11340/S galvanometer modulator | $\pm 10$μV to $\pm 10$mV | better than $\pm 2$μV/24 hrs. | $\pm 3$ pc. | 1mA gives f.s.d. on recorder for 100μV | meter, recorder outputs | also a microvoltmeter and null detector |
| **Southern Instruments Ltd.**<br>*Camberley, Surrey* | linear | MR 514 chopper | millivolt level impedance 0·22M Ω | <50μV referred to input | $\pm 5$ pc. | 20V max. peak-to-peak | meter, recorder outputs | normally followed by power amplifier for recorders and CRO'S |
| **Sunvic Controls Ltd.**<br>*Essex Steet, London, W.C.2* | linear | chopper | 0-0·1mV to 0–100mV | $\pm 1$μV/1000 hrs. on 1mV range | | 5–0–5 mA through 5000 Ω | moving coil indicator | input impedance 1–14 kΩ depending on range |

## SHUT-DOWN AMPLIFIERS

| FIRM | TYPE | RANGE OF INPUT VOLTAGE OR CURRENT SETTING | STABILITY | TRIP MARGIN INDICATION | CONTACT FACILITIES | TRIP SETTING | OTHER NOTES |
|---|---|---|---|---|---|---|---|
| **Bailey Meters & Controls Ltd.** *Purley Way, Croydon* | linear or backed-off linear | 0–30 $\mu$V in 3 ranges 0–150 $\mu$A in 4 ranges | $<5\mu$V/week | yes | 4M, 4B, 2 CO 3B or 1 CO | | |
| **Ekco Electronics Ltd.** *Southend-on-Sea* | PEM 1462 linear, valve | 0·1–12 MW | $<\pm 0{\cdot}1$ pc. | | 4B | | fail-safe, tropicalized |
| | N637 linear, valve | $10^{-12}$–$10^{-5}$ amp. | 0·1 pc. | meter percentage level | 4B | | low-flux facilities |
| **Elliott Bros. (London) Ltd.** *Century Works, London, S.E.*13 | mechanical chopper and valve | $2{\cdot}5\times10^{-7}$ amp. f.s.d. | 1 pc. f.s.d. | meter percentage deviation | 2 pairs CO | manual 90 pc. steps to f.s.d. | alternative f.s.d. sensitivities for $2{\cdot}5\times10^{-6}$–$2{\cdot}5\times10^{-4}$ amp. |
| **Ericsson Telephones Ltd.** *Beeston, Nottingham* | 129A self-rectifying chopper | | 0·1 pc. for setting $<\frac{1}{3}$ f.s.d. | $\pm$10V output representing $\pm$5 pc. deviation | | up to f.s.d. from 1/15 in steps of 1/150 f.s. | |
| **General Radiological Ltd.** *Great Portland Street, London, W.*1 | NE 048 50 cps. mechanical chopper | up to 3V f.s.d. | $\pm 0{\cdot}2$ pc. | 0–25 MW on meter | 2 pairs shut-down relay contacts. Excess margin alarm | 10 turn pot., e.g. 75 digits to 750 | |
| **Isotope Developments Ltd.** *Aldermaston Wharf, Reading* | 603, 603B valve | | $<1$ pc. trip/24 hrs. for constant current | percentage on meter | | 12 predetermined values | |
| **Labgear Ltd.** *Willow Place, Cambridge* | built to special order only | | | | | | |
| **Plessey Nucleonics Ltd.** *Weedon Road, Northampton* | PM 1018 chopper | 3 ranges 0–500kW or MW | Stab. of shut-down pt 0·4 pc f.s.power | meter 3 ranges $-5$ to 50 kW or MW | 2 pairs shut-down contacts | | similar to Harwell type 1520A |

## POTENTIOMETRIC PEN RECORDERS & INDICATORS

| FIRM | INPUT VOLTAGE OR CURRENT RANGE | BACKING-OFF FACILITIES | SCALE LENGTH | TIME FOR FULL SCALE | ACCURACY | CONTACT FACILITIES | RETRANSMITTING FACILITIES |
|---|---|---|---|---|---|---|---|
| **Bailey Meters & Controls Ltd.** *Purley Way, Croydon* | 0–8mV min. | yes | recorders 5 in. indicators 4 in. and 8 in. | 1·5 sec. | 0·25 pc. f.s.d. | 2 high or 2 low, or high and low | no |
| **Elliott Bros. (London) Ltd.** *Century Works, London, S.E.*13 | 10mV f.s.d. with 100 $\Omega$ impedance | as required | 10·75 in. | generally 2 sec. | 0·1 pc. | yes | slide-wire |
| **Foster Instrument Co. Ltd.** *Letchworth, Herts.* | 10mV, 50 amp. | yes | 8 in. | 8 sec. | $\pm 0{\cdot}25$ pc. | 4 $\times$ single-pole CO | slide-wire |
| **Honeywell-Brown Ltd.** *Greenford, Middlesex* | 1–100mV | yes | 11 in. | $\frac{1}{4}$ to 30 sec. | $\pm 0{\cdot}2$ pc. of span | yes | yes |
| **George Kent Ltd.** *Luton, Bedfordshire* | 2mV–2V with source impedances up to 500 $\Omega$ 30mV–2V up to 10M $\Omega$ $3\times10^{-9}$ amp. upwards | yes ; starting point up to 3 times span | circular 25 in. straight 10 in. | 2 sec. min. 15 sec. also standard | $\pm\frac{1}{2}$ pc. to $\pm\frac{1}{4}$ pc. | alarm contacts or electric on-off pneumatic three-turn control | slide-wire or pneumatic (3–15 psi. signal) integrator available |
| **Integra, Leeds & Northrup Ltd.** *Edgbaston House, Birmingham* 15 | 2mV–2V with source impedances up to 500 $\Omega$ $3\times10^{-9}$ amp. upwards | yes | circular 25 in. straight 10 in. | 2 sec. min. | $\pm\frac{1}{2}$ pc. to $\pm\frac{1}{4}$ pc. f.s.d. | alarm contacts or on-off | slide-wire or pneumatic |
| **Philips Electrical Ltd.** *Century House, London, W.C.*2 | 1–500mV | yes | 25 cm. | 1 sec. | 0·25 pc. | yes | yes |
| **Sunvic Controls Ltd.** *Essex Street, London, W.C.*2 | 0–500 $\mu$V to 0–100mV | yes | $9\frac{7}{8}$ in. (250mV) | 1 or 2 sec. | 0·5 pc. | yes (4 max.) | yes (100 $\Omega$) |

ABBREVIATIONS B *break* M *make* CO *change-over* RPM *reactor period meter* SNSM *slow neutron survey meter* PEM *power error meter* RP *reactor power*

| NTACT ILITIES | TRIP SETTING | OTHER NOTES |
|---|---|---|
| 3, 2 CO 1 CO | | |
| | | fail-safe, tropicalized |
| | | low-flux facilities |
| CO | manual 90 pc. steps to f.s.d. | alternative f.s.d. sensitivities for $2{\cdot}5 \times 10^{-5}$ – $2{\cdot}5 \times 10^{-4}$ amp. |
| | up to f.s.d. from 1/15 in steps of 1/150 f.s. | |
| shut-down ontacts. margin | 10 turn pot., e.g. 75 digits to 750 | |
| | 12 predetermined values | |
| | | |
| shut-down | | similar to Harwell type 1520A |

## ATORS

| RACY | CONTACT FACILITIES | RETRANSMITTING FACILITIES |
|---|---|---|
| f.s.d. | 2 high or 2 low, or high and low | no |
| | yes | slide-wire |
| c. | 4 × single-pole CO | slide-wire |
| of span | yes | yes |
| o ± 1 pc. | alarm contacts or electric on-off pneumatic three-turn control | slide-wire or pneumatic (3–15 psi. signal) integrator available |
| o ± 1 pc. | alarm contacts or on-off | slide-wire or pneumatic |
| | yes | yes |
| | yes (4 max.) | yes (100 Ω) |

PEM *power error meter* RP *reactor power*

**Nuclear Power**
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

# DATA SHEET 6

# D.C. amplifiers for nuclear reactors

*a survey of amplifier units, shut-down amplifiers and potentiometric recorders and indicators made by a representative cross-section of British manufacturers*

**Previous data sheets in this series**

1 Microscopic cross-sections of elements for thermal neutrons *May 1956 Vol I No 1*

2 Zirconium and Zircaloy II—mechanical properties *June 1956 Vol I No 2*

3 Neutron diffusion formulae *July 1956 Vol I No 3*

4 Bessel functions *December 1956 Vol I No 8*

5 Beryllium—physical and mechanical properties *October 1957 Vol II No 18*

*Copies of this data sheet may be obtained from* Nuclear Power, 3 Percy Street, London, W1 6d post free

but it limits the maximum attainable input resistance. When a high impedance input is required, as in the measurement of ion chamber currents, the transformer is omitted. The contact modulator or 'chopper' itself usually consists of a vibrating contact system driven from an electromagnet. Some modulators used are basically high speed relays while others are instruments designed specially for this service. There are two main sources of zero error and drift with contact modulators. One is caused by thermo-electric voltages generated at the contact and in the contact circuitry and it is difficult to reduce this below 0·1 $\mu$V per day. The other source of error is caused by coupling from the driving electromagnet coils. This coupling is usually considered in the design of the chopper and special shielding is provided to minimize it, the problem being particularly severe in the case of high impedance chopper amplifiers.

## 3. HIGH IMPEDANCE AMPLIFIERS

### 3.1 Direct coupled valve amplifiers

Multistage d.c. amplification can be obtained from valves using directly coupled stages, the difference in potential between anode of one stage and grid of the next being made up by a floating battery or resistive potential divider and negative line. In practice, the second scheme as shown in figure 4 is usually the more convenient and is almost universally adopted. With the single sided arrangement

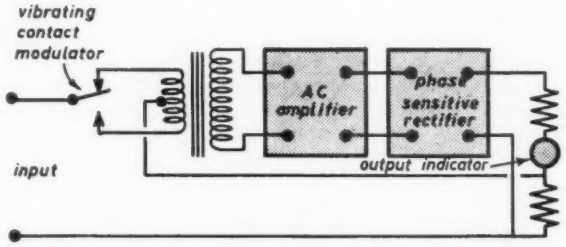



**Fig 3** The contact modulator, most widely applicable method of d.c. to a.c. conversion, employs an interrupter to chop the input into square wave form

shown, the input zero drift is fairly large. It is mainly due to heater voltage changes and is usually in the region of 10 mV for 1 pc change in heater voltage and 10 mV for 10 pc change in anode voltage. Such a performance is only acceptable in relatively simple instruments such as portable radiation monitors where high stability is not important. Even though the supply voltages are kept perfectly stable, there is some residual drift inherent in the valve circuits. For example, by the use of some refinements and stable supplies, one recently described amplifier has a stability of 2 mV over several hours (*3*).

By using two input valves as a balanced pair in a way which tends to cancel the drift, an input stability of 3 mV for 1 pc heater voltage and 1 mV for 1 pc anode voltage changes can be obtained. With stabilized heater and anode supplies, zero drifts can be reduced to 10 mV over 24 hours. If this drift can be allowed to represent 0·1 pc of the full scale deflexion, then the input sensitivity of the amplifier must be made to be 10 volts for full scale deflexion.

It will be seen that such an amplifier would be unsuitable for such applications as thermocouples, the output of which is of the order of millivolts. The high input resistance of valves, however, enables them to be used as current amplifiers with a shunt resistor of a very high value. For example, if a $10^{12}$ ohms resistor is used with a 10 volt input amplifier, the full scale deflexion would be $10^{-11}$ amp. Clearly the input resistance of the valve has to

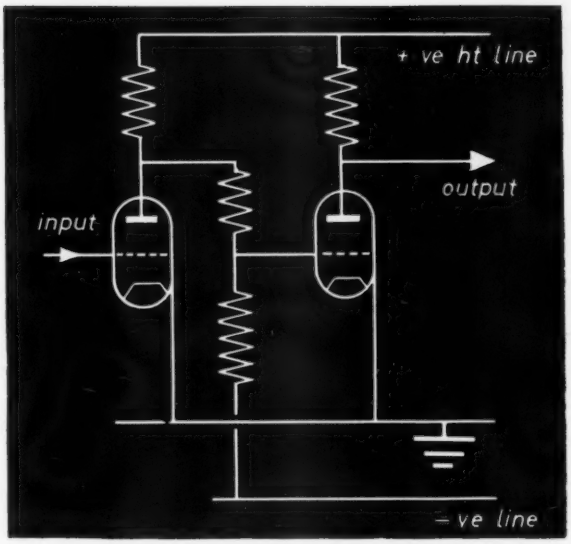



**Fig 4** With interstage valve direct coupling for multistage d.c. amplification, input zero drift is fairly large and it is suitable only for relatively simple instruments such as portable radiation monitors

be high compared with the resistor value, i.e. the input grid current of the valve must be small compared with the current being measured (*4*).

In order to obtain high input resistances with valves, they have to be operated under special conditions, and much higher values can be obtained from valves specially designed for the purpose. These are called electrometer valves and are obtainable with grid currents of less than $10^{-14}$ amp and can be operated satisfactorily with resistors as high as $10^{12}$ ohm. With such high resistors, the response time becomes rather long if appreciable cable and ion chamber capacitance is connected across the input. For example, 100 pF (5 feet of typical cable) gives a time constant of a 100 sec with $10^{12}$ ohm i.e. 500 sec for the reading to reach 99 pc of its final value. This can be reduced by feed-back by a factor of 100. Nevertheless, it can be seen that the large input voltage necessary to swamp zero drift in these amplifiers implies high values of input resistors and long time constants. This effect is reduced if the zero drift can be improved.

High value resistors are made from special materials which have a lower degree of stability and higher temperature coefficient of resistance than metals. Metallic wire-wound resistors are convenient up to values of a few megohms, so that an amplifier which uses such resistors as its input shunt has an advantage over one which necessitates higher valued resistors which are inevitably less stable and accurate.

### 3.2 High impedance modulators

As with the low impedance amplifiers discussed earlier, better voltage stability can be obtained if a d.c. to a.c. conversion technique is employed.

#### 3.2.1 Contact modulators

For the higher current ranges, special contact modulators can be used and when operating as current amplifiers are found to have a noise level in the region of $10^{-11}$ amp, i.e. $10^{-8}$ amp can be accurately measured. It is also possible to use the contact modulator to correct the drift of a direct coupled valve amplifier (*1*).

High impedance contact modulator and drift corrected amplifiers have found application in equipment for mea-

suring neutron flux in the upper three decades of reactor power. An associated requirement is the measurement of small deviations from a fixed power level. This 'backed-off' power measurement demands a high order of stability from the d.c. amplifier and its input resistors. The required performance can be obtained from high impedance contact modulators or drift corrected amplifiers. The latter have a better frequency response which is an advantage if the backed-off power is also used to provide an error signal for a servo loop for keeping the reactor flux constant (*5*).

The high impedance contact modulator amplifier can be incorporated in a potentiometric pen recorder so that the facilities of measurement and recording are provided in one instrument. This technique can be used for both linear power and backed-off power channels (*6*).

#### 3.2.2 Capacitance modulator electrometer

In this instrument, the current $I$ to be measured is passed through a high valued resistor $R_1$ and the voltage $IR_1$ across it is measured by a capacitor modulator. The input point is isolated from the varying capacitor $C_V$ by a resistor $R_2$ as shown in figure 5, and is of such a value that the time constant $R_2C_V$ is large compared with frequency of modulation of the capacitor. Under these conditions, when the value of the capacitor is varied, an alternating voltage is developed, which can then be amplified by an a.c. amplifier. A convenient form of varying capacitor is formed by a steel reed vibrating near a fixed anvil,

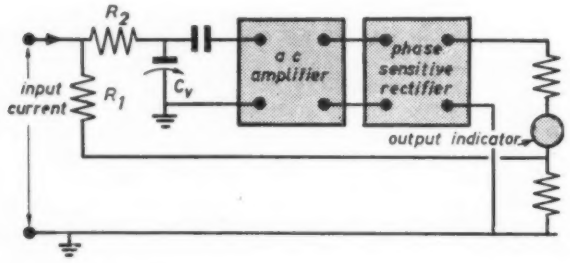



**Fig 5** In the capacitance modulator electrometer, the voltage drop across a high resistance is measured by a capacitor modulator which, with the arrangements shown, gives an alternating voltage when it is varied

the device then being known as a vibrating reed modulator (*7*). The vibration is maintained by a coil carrying a.c. near the reed. These are available commercially as a plug-in unit.

The modulator output is fed into an a.c. amplifier which is followed by a phase sensitive rectifier. The effects of internal noise and interference are reduced by restricting the bandwidth of the a.c. amplifier and rectifier; overall d.c. feedback is applied to linearize the system and improve the response time.

The main source of zero drift of these amplifiers is due to contact potential changes originating at the vibrating reed electrodes, but this is reduced to about ·1 to 1 mV per day in commercially available units. Assuming a volt drop of 100 mV across the input resistor, this corresponds to 0·1 to 1 pc drift per day. Modulator insulation resistances of $10^{15}$ ohm are attainable so that it is possible to use input resistors of up to $10^{12}$ ohm with negligible error.

## 4. POTENTIOMETRIC SERVO RECORDERS AND INDICATORS

In these devices, the d.c. to a.c. conversion device and a.c. amplifier are followed by an electric motor instead of the phase sensitive rectifier. This motor is made to operate

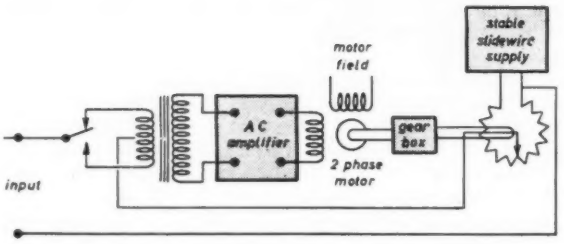



**Fig 6** This is the general circuit for potentiometric servo-operated recorders and indicators in which the phase sensitive rectifier following the d.c. amplifier is replaced by a 2-phase motor

a slide wire and the voltage tapped off is fed back to oppose the input voltage as shown in figure 6. It will be seen that if the a.c. amplifier gain is high, the motor will rotate until it finds a position where the difference between feedback and input voltage is small. At this point the motor stops and the position of the slide wire will be related to the input voltage. If the slide wire is linear and the current is maintained constant, the position of a pointer moved by the motor will be proportional to the input. In the case of recorders the pointer also carries a pen moving over a suitable chart and by suitable switching, multipoint recording is performed.

It will be seen that the device is a self balancing potentiometer and that the current is very small at balance, so that the voltage measurement is made without loading the input circuit. This property and its high stability and accuracy make it ideal for use with thermocouples. The balance is not perfect, however, and above a certain value the resistance of the input circuit causes a 'dead spot' with subsequent loss of accuracy. Details of design and performance of servo-operated recorders are given in extensive reviews by Maddock (*8*) and by Medlock and Kealy (*6*).

The conventional recorder usually employs a transformer between the chopper and a.c. amplifier. By using a special chopper feeding directly into the valve amplifier, as already described, a high impedance recorder can be designed (*6*). Where extremely high input resistances are required, a capacitance modulator can be used instead of the contact modulator type (*9*). As an alternative to the graphical display it is possible to record information on electric typewriters. The necessary analogue to digital conversion can be performed by a shaft digitizer mounted on the slide wire shaft.

## 5. LOGARITHMIC AMPLIFIERS

For some purposes, it is desirable that an amplifier be used which has an output which is proportional to the logarithm of the input.

In nuclear reactors, neutron flux measurement must be provided over at least 6 decades and it is convenient to have this displayed on a single scale. The differentiated output of such an amplifier with respect to time is also used to indicate the reactor doubling time and operate protection equipment if the reactor is diverging too rapidly (*5*). A similar situation arises in the handling of large gamma ray sources where it is convenient to have a dose-rate meter which has a wide range on one scale. In one instrument, a range of 10 mR/h to $10^5$ mR/h is covered with a logarithmic scale (*10*).

Such a logarithmic characteristic can be obtained from a thermionic diode working in the retarding field region, but the arrangement is rather sensitive to heater voltage variations which limit the accuracy of the system. A better arrangement, due to R. J. Cox of Harwell, employs a

pentode connected with a feedback amplifier to maintain constant anode current by controlling the screen grid voltage (5). With this system the relation between grid current and screen voltage is logarithmic over the range $5 \times 10^{-12}$ amp to 50 microamp and the stability is about 4 pc of a decade for heater voltage variations of 10 pc. Such a logarithmic stage can be used with an ion chamber or it can be fed from a diode to form a logarithmic rate-meter for the measurement of pulse rate from a counter.

A logarithmic scale can be obtained on potentiometric recorders by using a slidewire with a logarithmic law instead of the usual linear one (9).

### 6. TRANSISTOR d.c. AMPLIFIERS

The reputation for high reliability of transistors compared with thermionic valves makes them attractive for applications where reliability is at a premium. Apart from their obvious advantages in portable instruments, their low power dissipation also allows convenient mounting arrangements in panel mounted gear and gives considerable space economy together with the elimination of any necessity to provide the cooling air supply often required with equipment containing thermionic valves. Another advantage is that the supply voltage can be obtained from a battery, so making the equipment independent of mains supply failures.

Transistors can be used in direct coupled amplifiers which are the equivalent of the thermionic valve amplifiers described in section 3.1. In common with their valve counterparts, transistors in such circuits exhibit input drifts, the origin of which is found to be mainly due to temperature changes. This problem has been investigated in detail by Chaplin and Owens (11) who find that in a typical single transistor input stage the voltage and current drift referred to the input is 100 mV and 50 μA respectively. By balancing two transistors and by adjustment of the components this can be reduced to corresponding figures of 2 mV and 1 μA. It will be seen that the voltage drift figure is comparable with that obtained from valve amplifiers but the current drift is much greater than for valves.

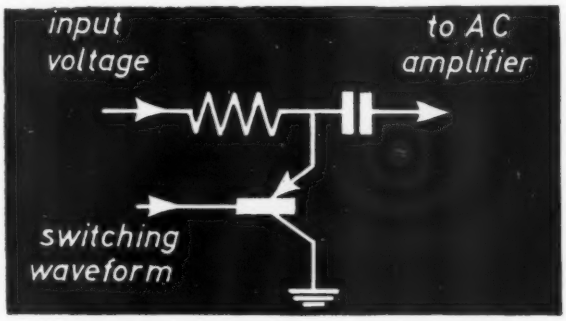



**Fig 7** Transistors can be used as switches as an alternative to mechanical contact modulators. The switching wave form is best applied to the base of the transistor as shown and the input and output waveforms taken from the emitter

Transistors can be operated so that they act as switches when a suitable wave form is applied to the transistor base electrode. This switching property enables them to be used as an alternative to the mechanical contact modulator giving the d.c. to a.c. conversion described in Section 2.2.2 without the moving parts inseparable from the mechanical chopper system.

Two methods of connexion of the transistor can be used but it is found that the better is one in which the switching waveform is applied to the base with the collector earthed. The input and output waveforms are taken from the emitter as shown in figure 7. With this arrangement, input drifts of 100 μV and $4 \times 10^{-9}$ amp have been obtained with a completely transistorized amplifier (12). By using silicon instead of germanium transistors, it is predicted that the current drift can be further reduced (12).

It can be seen that even with germanium transistors a performance is obtainable which compares favourably with valve types for many applications. For example, a 100 μV input stability corresponds to a temperature of 2·5 °C with a chromel-alumel thermocouple. The input stability of $4 \times 10^{-9}$ amp allows such an amplifier to be used with an ion chamber, the drift being small compared with the 1-100 μA commonly obtainable from chambers working with reactors near full power.

### 7. SHUTDOWN AMPLIFIERS

In addition to the indication and recording equipment, instruments are also required to operate the alarm and safety circuits if the neutron flux or temperature of certain parts of the reactor exceed some preset value. In some cases, a reactor shutdown is initiated by these amplifiers.

Neutron flux shutdown amplifiers operate from ionization chambers, the ion current being passed through a resistor. The voltage drop developed across this is then compared with a preset voltage and if the ion chamber signal exceeds this, a trip signal is passed on the reactor safety and alarm circuits. The difference between the voltage developed by the ion current and the preset voltage has to be amplified before it can operate the final relay. Two types of amplifier are in common use (5), one being the direct coupled valve amplifier system and the other a high impedance contact modulator and a.c. valve amplifier. Owing to the higher stability of the latter arrangement, it is possible to operate it with the trip setting very close to the working value.

In both cases these instruments are designed with special circuitry so that there is only a very small probability that a fault occurring in them will not give an alarm signal, i.e. the equipment tends to fail safe. Another feature is a meter which displays the trip margin, i.e. the margin between actual power and the trip setting. In the case of gas-cooled reactors it can be shown that the output of a tacho-generator attached to the gas coolant circulator shaft gives a voltage proportional to the reactor power. This voltage can be used as a variable trip level so that the trip margin is kept constant for different reactor power outputs.

With the introduction of the transistor chopper, shutdown amplifiers are now available using this type of input stage. For example, one such amplifier has an input stability of 100 μV with a trip level variable over the range 0-100 mV. These characteristics make it a convenient unit for use with thermocouple initiated trip signals caused by the various overtemperature conditions which can occur in the reactor.

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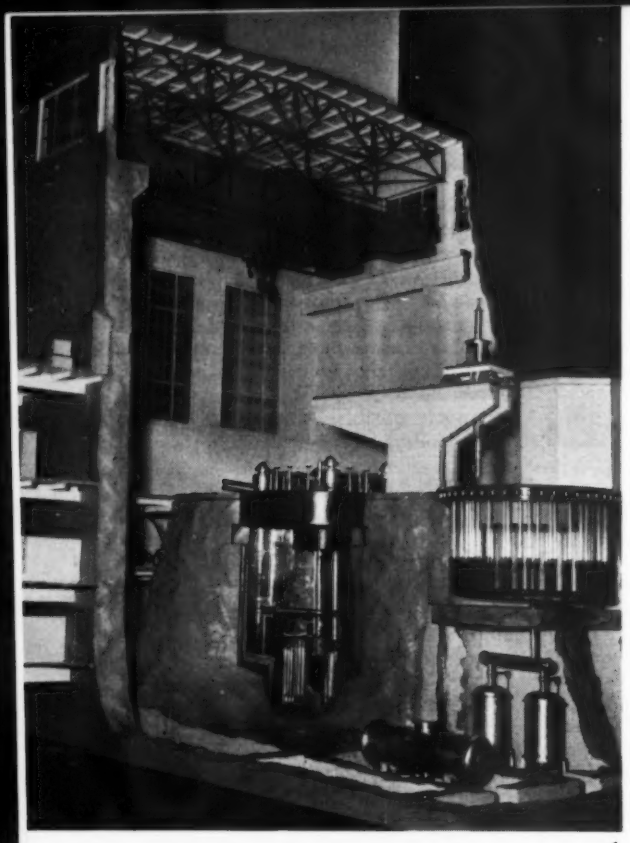
# On show at Brussels

## Nuclear models seen at the e



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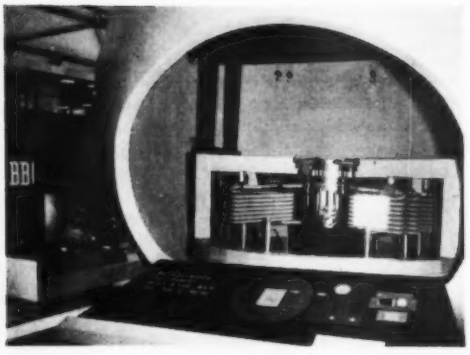

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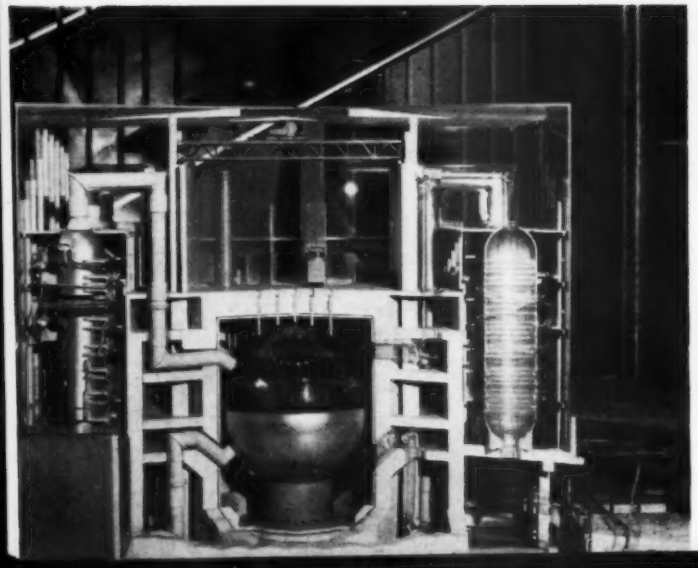

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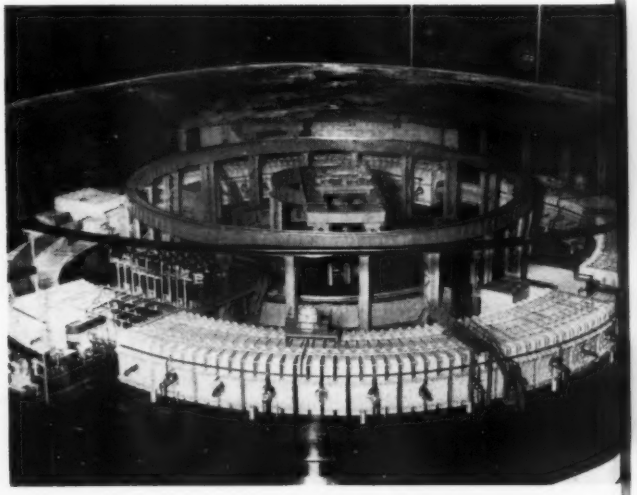

**1.** The projected Russian 50 eMW fast breeder research reactor to work on Pu-239 and U-238 which like Dounreay will be cooled by liquid sodium. With it the Russians will be able to investigate attainable breeding ratios and problems of control and stability **2.** The Dounreay experimental fast breeder reactor **3.** One of the reactors of the nuclear power station under construction at Hinkley Point by the English Electric, Babcock & Wilcox and Taylor Woodrow Atomic Power Construction Co Ltd. The flow of coolant gas through the reactor and of steam to the turbines is traced in coloured light tubes. When completed it will be the largest nuclear power station in the world with an output of electricity 30 pc greater than the highest recorded consumption of the whole city of Brussels **4.** The Russian 10 GeV proton synchrotron which went up to full power a year ago at the Dubna centre of the Joint Institute for Nuclear Research. Said to be the largest accelerator in the world it is designed eventually to reach 10,000 MeV. The 200 ft dia magnet weighs 36,000 tons **5.** A water reactor by US Westinghouse **6.** Sir Claude Gibb, chairman of the Nuclear Power Plant Co, inspects a model of his company's nuclear power station under construction at Bradwell. The reactor shown is sectionalized and the coolant gas indicated by neon tubes; the other contains the NPPC stand office. **7.** The zero energy high temperature gas cooled reactor being built at the UK Atomic Energy Authority's research centre at Winfrith Heath by the General Electric Co. It will use ceramic fuel elements—probably a mixture of graphite, uranium and thorium **8.** The recently launched Russian icebreaker *Lenin* which will have a pressurized water reactor of the American type.

at the exhibition

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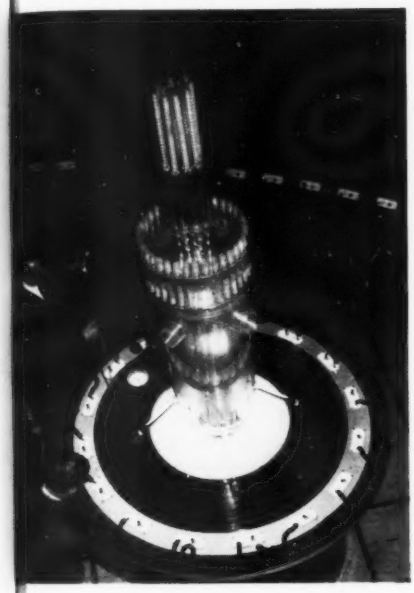

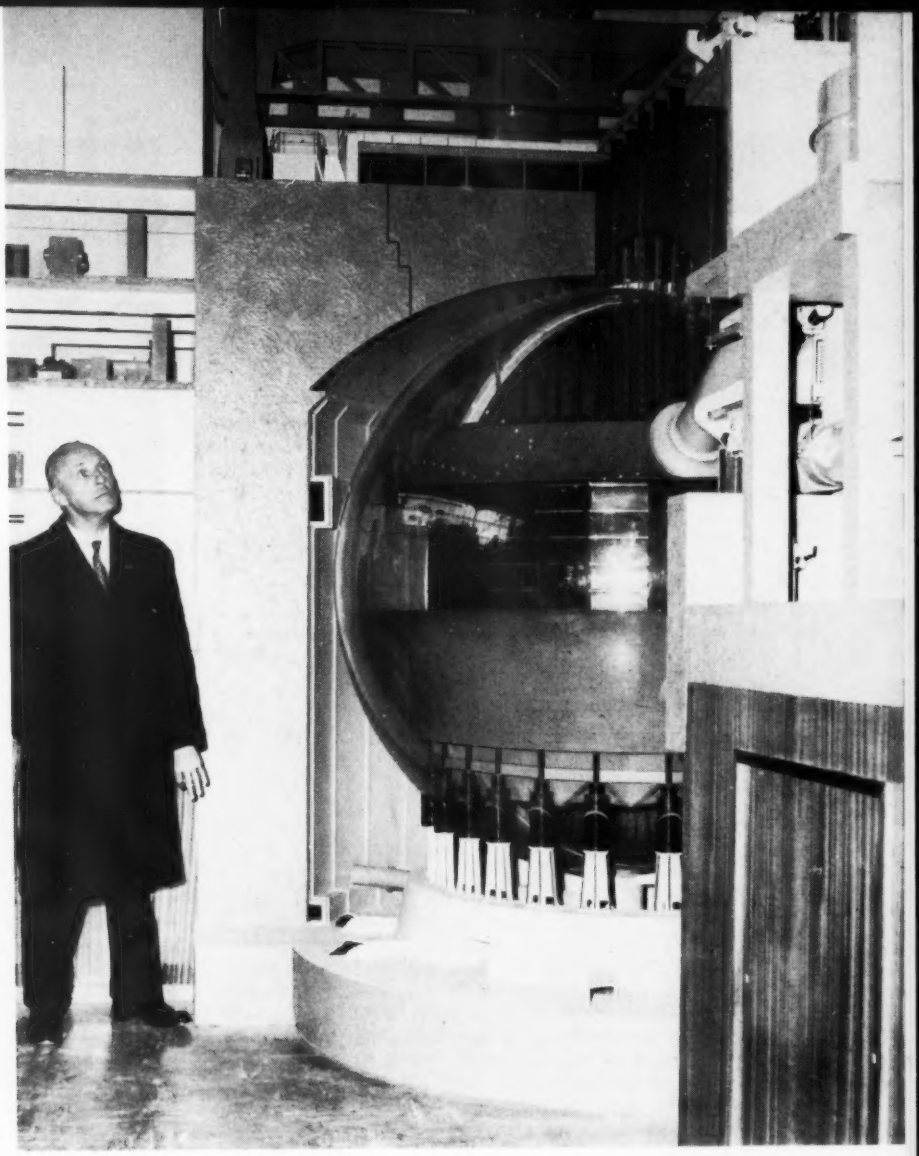

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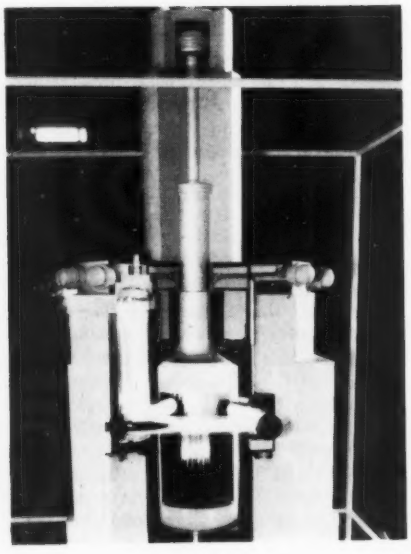

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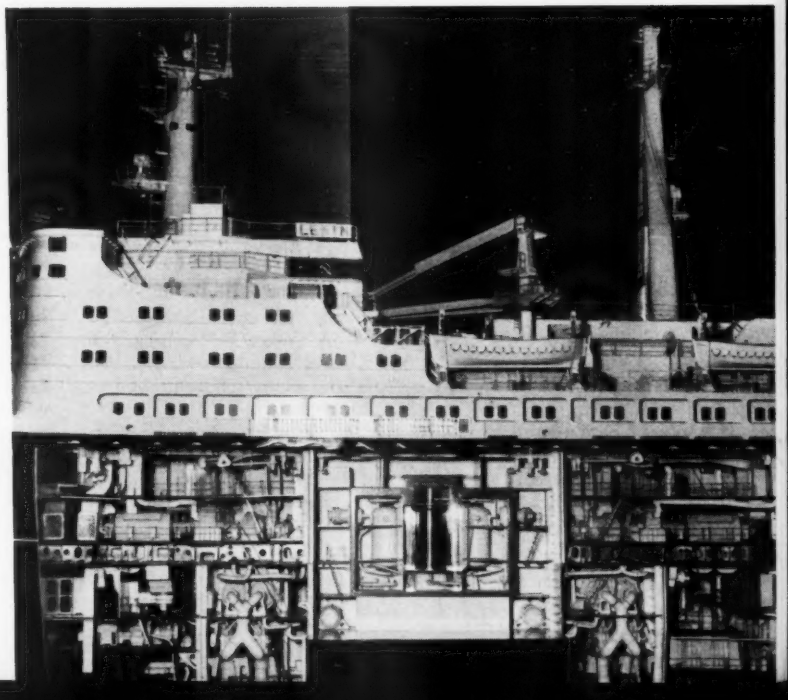
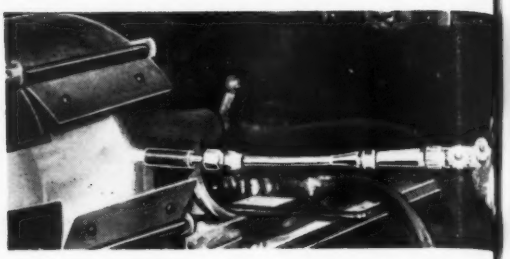


Regular meetings are now held between the AEA and members of the chemical industry to assist them in entering the nuclear field. Many of the industry's new techniques will be on show at the first



DELORO STELLITE
Fusing the powder on a work piece

# Chemical & Petroleum Engineering Exhibition

OLYMPIA JUNE, 18-28, 1958

IN THE LAST DECADE a very large amount of new plant for manufacturing chemicals, including petroleum products and derivatives, has been installed in Great Britain. The development of the nuclear energy programme has called for new equipment and new techniques from the chemical engineering industry. This year some three hundred firms will show their achievements at the Chemical and Petroleum Engineering exhibition—the first of its kind. It will be held at Olympia from June 18 to 28 and will include a conference on the organization of chemical engineering projects, arranged by the Institution of Chemical Engineers. In this preview we give details of some of the exhibits likely to be of interest to nuclear engineers.

A first public showing will be a model of a commercial heavy water plant designed by Petrocarbon Developments Ltd. Developed in close cooperation with Harwell, and cleared for the exhibition a few weeks ago, the plant is for distillation of hydrogen at $-253°C$ to produce deuterium which is then burned with oxygen to give heavy water. It incorporates the results of years of work on problems like obtaining a high purity feed gas by freezing out impurities in reversing heat exchangers and regenerators. Refrigeration is produced by expansion turbines and pressures below 10 atmo are employed giving low compression costs and minimum maintenance. Engineering contractors are Simon-Carves Ltd who on their own stand are exhibiting a 6 ft high model of the 320 MW nuclear power station under construction at Hunterston in collaboration with General Electric. The DIDO research reactor will be represented by a model on Head Wrightson's stand. The fifth reactor of the DIDO-PLUTO type is being manufactured now for Denmark, and work will begin soon on the one for West Germany. Another exhibit will be a one-eighth scale working model of their induced draught cooling tower.

Very conspicuous will be a 30 ft-high Perspex 'Spraypak' tower by Constructors John Brown Ltd. It will be working under full load conditions and closed circuit television cameras at various points on the tower will give an opportunity of studying the contraflow action inside from eye-level screens. A subsidiary company—Cathodic Corrosion Control—will highlight the latest methods of combating corrosion in many different circumstances.

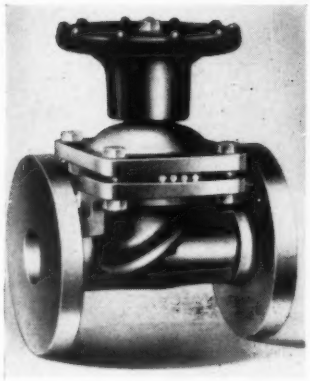
Engineers interested in the problems of designing valves to handle corrosive fluids will get a view of the Meynell 'rayon-patent' stop valve for the first time. It was developed on the Continent and the company have just obtained sole manufacturing rights for England and the Commonwealth. The upper part of the rubber valve is so shaped that movable parts remain isolated from the liquid—which can be at temperatures up to $212°F$—so that packing glands are unnecessary and design eliminates pressure on that part of the nylon clack separating the fluid controlled from the working mechanism. Another new valve is a forged steel bonnetless gate type for temperatures up to $900°F$ at 1500 psi by British Steam Specialties Ltd. Angle valves on show for pressures up to 5400 psi at $1200°F$ feature temperature-normalizing fins or bellows-seal steam assemblies. Electrical operation is now available for all sizes of Saunders' diaphragm valves from 0·5 to 12 in. and will be demonstrated by a 2-in. type wired for push-button control. Pressure operation will be represented by working models of both pressure opening (with automatic safe closure) and pressure closing—both these types being operated by overhead diaphragms—with open and closed positions indicated electrically. The Talbot Stead Tube Co will exhibit what is claimed to be the first three-way diaphragm valve in the world. There is no mechanism in the fluid and one nut clamps together the whole of the assembly. A selector device indicates which side of the valve is closed. Also shown will be a $7\frac{1}{2}$ ft-high model of the No 1 reactor at Calder Hall, for which the company supplied several miles of tubing.

Corrosion is a frequent source of trouble in pipe line insulation and a method of overcoming it cheaply is offered by Cape Asbestos Ltd in their rigid pipe sections of *Rocksil*. These 3 ft-long sections are designed for temperatures up to $600°F$. For cleaning internal surfaces of tubing a new technique in which the tube itself is used to form a blast box by coupling vacuum and blast hoses to opposite ends will be exhibited by Vacu-blast Ltd.

### Electric heating applications

Engineers unfamiliar with the latest developments in electric surface heating will find some interesting exhibits on Isopad's stand. The central display will be a heater for testing 15 ft-high 60 in.-bore valves for atomic power stations. Also on view will be *Isojackets* for controlled heating of the type successfully used in the regeneration of rare gases at nuclear plants. More applications of electric heating will be shown by the Stabilag Co. A pilot plant gas-purged heater will be demonstrated with the object of showing how electric jacketing can safely be used for heating purposes in a fire-hazardous area. Fea-

ISOPAD
Isojacket for high temperature work



MEYNELL
' Rayon-patent ' stop valve

tures are multi-zone wall heating and special valve control for inert gas release in case of vessel fracture.

Many pumps will be on show at the Exhibition. Hayward Tyler, for example, exhibit glandless motor units for boiler circulator and reactor coolant systems and loop tests. For handling hydrofluoric acid in all concentrations at heads up to 160 ft Appleton & Howard display their submersible centrifugal pump. It incorporates a special design of pure solid p.t.f.e. submersible bearings which have operated successfully at speeds up to 2900 r.p.m. On the stand of Rhodes, Brydon and Youatt, a vertical pump will be seen in operation extracting molten metal from a tank. Two fractionating diffusion pumps—of 9 in. and 2 in. bore—will be shown by Edwards High Vacuum. Jet assemblies are specially arranged to get the purest oil only maintained in the high vacuum stages, and an ultimate vacuum of better than $5 \times 10^{-7}$ mm.Hg while retaining good backing pressure is claimed. The larger models are used for particle accelerators and for this work are fitted with refrigerated chevron baffles and gate valves. A working model of a new self-priming centrifugal pump capable of drawing a high vacuum and delivering against heads up to 60 ft will be shown by Girdlestone Pumps.

Those interested in high pressure pumps will be able to see a newly developed special diaphragm model among the exhibits of ECD Ltd. It can be designed to meet individual specifications and is able to withstand up to 2000 psi.

Among the air compression equipment on show will be a rotary model which eliminates the necessity for aftercoolers by using oil cooling to provide a final air temperature of less than 200°F. This recently-introduced type by Worthington-Simpson has a displacement of 200 cu ft/min at a pressure of 120 psi. Some entirely new lines on view will include the Consolidated Pneumatic Tool Company's class P6 range of stationary compressors.

Process measurement and control instruments will be well represented. The main emphasis of the George Kent display will be on practical demonstrations of the interchangeability of standard units. Possible alternative combinations available are claimed to run into hundreds of thousands. New equipment exhibited by Foxboro-Yoxall will include a direct-mounted liquid-level transmitter for open or closed vessels to transmit an output air signal direct to standard 3-15 psi receivers, recorders, and controllers. The sensing diaphragm capsule of this force-balance instrument is flange-mounted to the side of the tank and there are no process piping difficulties.

A new solution to filtration problems where contact of the process material with metals must be avoided will be offered by the Dorr Oliver Co with their first showing in this country of a rotary vacuum drum filter in p.v.c. For testing small quantities of a variety of substances Endecotts (Filters) have developed a pocket-size sieve for use with interchangeable rimmed gauze disks. One of the techniques used by Birlec Ltd to produce a small laboratory dryer capable of reaching very low dewpoints is a type using molecular sieves as the adsorbent. Also exhibited will be a scale model of their newly-designed neutral-gas generating plant. The processes involved in gas diffusion, removing suspended solids from liquids and filtrating compressed air will be demonstrated on a working model by Doulton Industrial Porcelains Ltd.

Exhibits of interest to welding engineers will include a photographic enlargement of the fabrication of the MERLIN II reactor among the APV Co's display of aluminium and stainless steel welded fabrication. A 23 ton welded vacuum/pressure vessel will be shown by G. A. Harvey & Co (London) together with a section of a high pressure vessel set up for radiographic examination of the welds using equipment of Nuclear Engineering Ltd. Electrodes produced to meet the stringent requirements of the Atomic Energy Authority will be shown by Murex Welding Processes Ltd, including equipment used for welding the stainless steel vessel of the Dounreay fast-breeder reactor. Another firm taking a prominent part in nuclear work—Quasi-Arc Ltd—whose equipment is used for welding the heat exchangers for Berkeley power station—will display a wide range of equipment including new types for shielded inert gas metal arc-welding designed with lightness and portability in mind, incorporating remote control of welding current and wire feed.

The techniques used by Whessoe Ltd in their construction of the pressure vessels for Bradwell nuclear power station have not yet been disclosed, so a statement by the company that they will be illustrating these at the exhibition is particularly interesting.

Hardfacing of sleeves by metal spraying will be demonstrated by Deloro Stellite. It is claimed to be an advance on normal cold spraying because the alloy deposited is actually welded on the base metal.

### Nuclear metals on show

Forged steel work on view will include a sectioned portion of a 26 ft long high pressure boiler drum by the English Steel Corporation.

The use of graphite as a constructional material will be well illustrated by a 6 ft long heat exchanger by Powell Duffryn Carbon Products Ltd which provides 200 sq ft of exchange surface. A full size Perspex working model of a 50 sq ft unit will demonstrate the working principle of cubic heat exchanger design.

Zirconium, niobium and tantalum are of increasing interest to the nuclear industry and wrought forms will be displayed by the Metals Division of ICI.

Manufacturers have to keep pace with the trend towards higher temperatures and one example of this is the latest development of their standard mechanical gland seal by Flexibox Ltd. After modifications including the introduction of a special cooled sleeve it is now claimed to operate without leakage at more than 800°F and 800 psig pressure.

Other interesting exhibits range from a working model of an industrial crystallization plant displayed for the first time by the Power-Gas Corporation and Ashmore, Benson, Pease & Company with samples of 35 different chemicals which have been crystallized in their apparatus, to a rotation sensing device by Londex Ltd.

# Gas-cooled reactor isolating valves

## new approach to the sealing problem

This 5 ft prototype valve shows clearly how the butterfly is pivoted on a bracket and operated by a linkage gear. The sealing ring, which is not shown, lies in a groove round the top face of the body

IN THE GAS-COOLED graphite-moderated reactor it is standard practice to include shut-off valves in each of the several parallel cooling circuits so that a particular heat exchanger and gas circulator can be isolated from the reactor vessel. This allows inspection, maintenance and repair to be carried out without having to shut down the whole plant. One of these valves is generally in the top, or hot, leg of the ducting and the other is in the return branch upstream of the blower. There is also usually a by-pass duct of smaller diameter and this, too, is fitted with an isolating valve. These valves are not used for control purposes, so the main design requirements are: minimal head loss when open, minimal gas leak when shut. Since the static pressure in the circuit is already around 150 psi and is likely to increase in later stations, this second requirement is not easy to meet in view of the size of the ducts (5 ft dia and above) and the high temperature (about 750°F) of the gas. Organic sealing materials are ruled out on account of the temperature and even the choice of metals is restricted on nuclear grounds (copper-based alloys for example are not allowed).

At Calder Hall and Chapel Cross, the 54 in. gas valves are of the wedge gate type operated by electric motor while some of the new CEGB power stations are using a type of butterfly valve with an eccentric spindle. Other types of isolating valves using flexible metal seals have also been proposed (NUCLEAR POWER, Sept '57, p. 379).

The problem has recently been receiving attention by Gordon Valves Ltd—a subsidiary company of the well-known valve firm of James Gordon & Co Ltd—and we recently visited the Stroud works of T. H. and J. Daniels Ltd where a prototype 5 ft dia valve has been made for Gordon's and is at present under development. Very briefly, it is a butterfly valve which is sealed in the closed position by using the principle of thermal expansion. This is done by means of an electrically-heated floating metal seating which is of slightly smaller diameter than the butterfly when both are at the same temperature. To effect a seal, heat is applied to the seating which expands and allows the butterfly to enter. The current is then shut off and the seating shrinks on to the butterfly, giving a metal-to-metal seal all round. To open the valve, the butterfly is freed by heating the seating. This sounds like a lengthy operation but the mass of metal in the sealing ring is not high and the whole operation only takes about one minute.

The valve itself is of interesting design. The butterfly is of cast steel and is hinged on a $3\frac{1}{2}$ in. nitralloy steel spindle carried on a cast steel bracket spanning the valve body which is of mild steel welded fabrication. The mounting spindle is fixed and thus takes no torque. Operation is by means of a linkage mechanism driven by a gland-packed shaft. In the prototype only a simple pneumatic cylinder is used but in the production model this will be replaced by $CO_2$-operated cylinder in a sealed housing so that there will be no leakage whatever. The edges of the butterfly are ground spherical and are hard chrome plated. In the open position, the butterfly fits neatly over the support bracket so that the aerodynamic losses are as small as possible.

The sealing ring is of rectangular cross-section with a pair of relatively thin rims which bear against the butterfly edge in the closed position. The ring is hollow and contains a heating element of chrome-nickel wire sheathed in a fused silica tube. This has three outlets which are connected to a 3-phase 440-volt supply and is designed to carry 35 kW as a delta-connected load. As an alternative, Gordons are working at a low-voltage heating system (7 V) using a tubular heating element.

To prevent leakage round the back of the sealing ring, it is connected to the valve body by means of a thin steel diaphragm of U-cross section welded to both ring and body. This provides a seal and yet allows the ring to expand radially. In the prototype the sealing ring is in 18/8 stainless but production valves will probably use an inconel material. It should be noted that since the ring is not rigid, the limits of circularity of the butterfly need not be particularly severe.

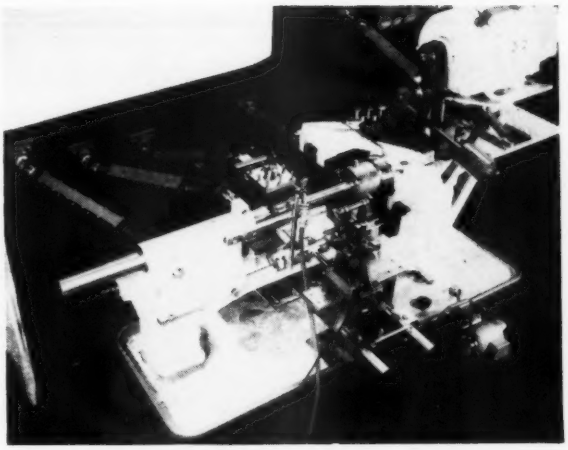
For test, domed ends are bolted to the valve body and leak tests are carried out by pressurizing the upstream side to about 200 psi and measuring the rate of pressure drop on that side and the rate of rise on the low pressure side. To simulate working conditions, the valve body is heated throughout by a series of resistance heaters. A small rotameter is also fitted in the low pressure side to record any gross leaks and also the rate at which sealing a tube takes place when the current is turned off. Results of these tests have been most encouraging and it is expected that leak rates of the order of $\frac{1}{4}$ lb/h will be attained.

# Developments in remote handling

## lathe for Dounreay

AMONG THE CALLS made on industry as the nuclear energy programme gets into its stride is a demand for machines to cope with remote-handling problems. One firm which has become interested in the possibilities of this work is J. Evans & Son Ltd of Portsmouth who have branched out from their established business which includes automatic brush making equipment, machine tools and a wide range of aircraft parts and hydraulic assemblies. Their first activity in the atomic energy field was the manufacture of zinc bromide viewing windows under contract from Pye. Thirty four have now been delivered to Dounreay and other equipment manufactured under contract includes a cutting and stripping machine for A. C. Wilson and Partners Ltd. This removes the nose and tail units of irradiated uranium fuel elements under water and then strips off the sheaths by means of an hydraulic ram.

In addition the company has now moved on to the design of their own machinery. As well as producing special equipment they are particularly interested in the adaptation of conventional machine tools for remote control. A few weeks ago their engineers installed one such device —a remotely controlled lathe adapted from a 3½ in. centre screw cutting and servicing lathe—in a research cave at Dounreay, and final tests are proceeding on site. It will be operated from behind a 4½ ft concrete wall to machine tensile test pieces from enriched uranium elements with the aid of a zinc bromide viewing window. We had the opportunity of seeing the completed lathe at the factory during a recent visit. All controls, such as tool travel, chuck tightening and feed are conveyed by rods, which are stepped to avoid radiation shine through along the shafts. Considerable ingenuity has been exercised in the transmission of movements, which necessitated divergences from conventional practice such as using a fixed tailstock and moving the spindle.



All lathe operations are transmitted from handles on the other side of a shielding wall by mechanical links and rods

Safety precautions include an arrangement which automatically cuts off power while the chuck or tailstock spindle is operated. Displacements are measured by a *Magnagage* and normal engineering tolerances can be obtained. Other equipment designed and in process of manufacture for Dounreay includes a general purpose cutting machine for slitting off stainless steel sheaths followed by slicing up of uranium fuel elements, and a 50-ton press for crushing elements for subsequent tests.

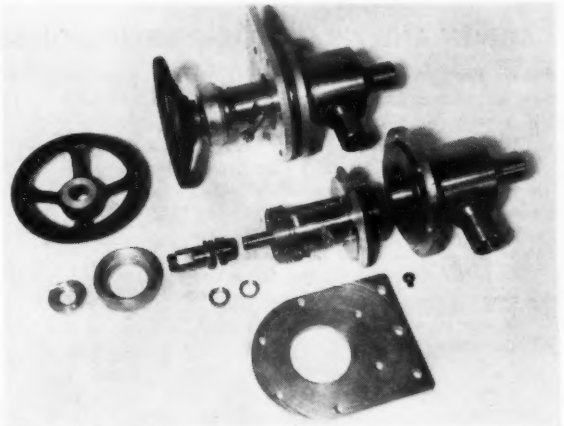
# From aircraft to atomic energy

## Surrey company's new interests

THE RAPID PROGRESS of atomic energy developments during this decade has called forth the resources not only of many large firms whose names are household words but also those of several quite small specialist companies whose roots often lie in the aircraft industry. Typical of these is Palatine Tool and Engineering Co Ltd of Surbiton who were originally jig and tool makers. About six years ago they first started to make valves of Harwell design for the Atomic Energy Authority and it led to further business of this type until now 95 pc of their work is nuclear.

Valves still remain Palatine's speciality, their main customer being of course the AEA. These are of various kinds—for gases, liquids and liquid metals—and are of the bellows-sealed, stainless-steel, zero-leak type. The bellows are made on special machines which edge-weld the pressed diaphragm from which they are formed. The inside welds are made first and each pair of plates is leak-tested with nitrous oxide before they are joined on the outside to form the complete bellows. Currently under development is a bellows-sealed valve for 2000 psi water, and one of nickel-free steel for bismuth. New types of bellows are given severe fatigue testing in course of development.

A 1 in. liquid metal pump by Palatine was described in NUCLEAR POWER in July 1957. During our visit to the firm we saw several of these units going through the shops. We also saw an electromagnetic flowmeter designed by Rolls-Royce. Other recent works include special glove boxes for Dounreay, helium driers for DIDO-type reactors to the design of British Oxygen Gases, and a small stainless-steel canned rotor pump for Harwell.



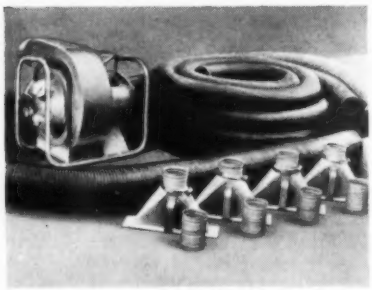
This 1 in. NaK valve of Risley design can work up to 450°C at 50 psi. It is of the bellows sealed type, argon sealed for leak detection, and incorporates a stellite faced plug

# New Equipment Survey

PLANT | INSTRUMENTS | MATERIALS

## CONFINED WELDING EASED BY MULTI-POINT EXHAUSTER

A portable welding fume exhauster was introduced recently by Keith Blackman Ltd which should do much to assist welders working in confined positions. Known as the *Tornado 4-way* fume exhaust unit, it consists of a centrifugal fan fitted with four inlets which may be connected by flexible hose to the places where the men are working. These hoses which may each be up to 30 ft long, are fitted with fishtail hoods and they can be attached to ferrous metals in any position by means of an exclusive magnetic device. The 6 in. discharge hose can be led off to any convenient position.



The Tornado 4-way extracts fumes from four welding positions

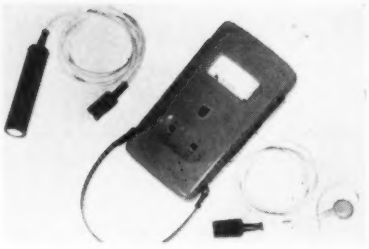
The fan is run at 2900 rpm by a 1 h.p. a.c. or d.c. motor and the complete unit can easily be handled by two men.

Similar units for special purposes can also be designed to order and the firm instance the case of one for a boiler manufacturer. Powered by a 3 h.p. motor, this unit removes 700 cfm and discharges through a filter.

Tick **No 129** on reply card

## RADIATION MONITOR IS TRANSISTORIZED, HAS PRINTED CIRCUIT

Philips Electrical Ltd have added to their range of instruments a new transistorized, printed-circuit pocket radiation monitor. Known as the type PW4014, this is a watertight, fully tropicalized instrument of rugged construction designed for the general survey, location and measurement of radioactivity. It weighs only 1 lb 5 oz and its small dimensions—6⅛ by 4 by 1⅛ in.—enable it to be carried easily in the pocket. A built-in geiger-müller tube permits the instrument to be used as a probe for measuring gamma radiation and a separate mica end-window geiger-müller tube with a flexible lead can be plugged into the instrument for beta measurements.



The Philips pocket monitor is supplied with a geiger-müller probe and earphone as extras

Two measuring ranges are incorporated: one for high and the other for low sensitivity. An accurately-balanced, easily-readable meter calibrated in mr/h (radium gamma radiation) indicates the radiation intensity. A small earphone can be connected for the audible detection of very low intensities. The power supply is a 3 V flashlight battery or two miniature 1·5 V cells. The all-transistorized circuit has a low drain, so that long battery life is assured.

In general, the PW 4014 is suitable for use in all cases where the indication and measurement of radioactivity is necessary or desirable. Typical applications are geological survey, location of missing radioactive material, checking of radioactive contamination, dose rate measurements involving personnel, intensity measurements in laboratories where there is a radiation hazard and monitoring of special tracer experiments.

The PW 4014 sells at £47 10s. 0d. (basic). Accessories include gm probe for beta radiation measurement £11 0s. 0d. and earphone £3 0s. 0d. Delivery is ex-stock.

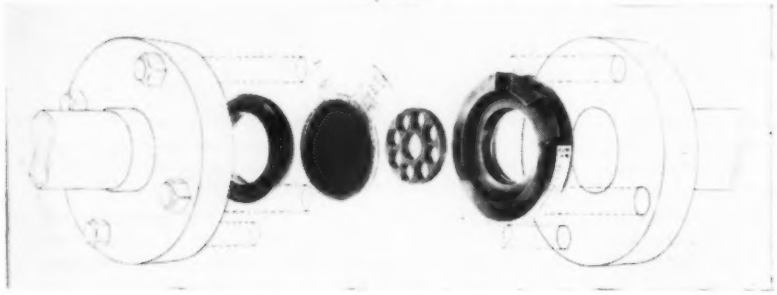
Tick **No 130** on reply card

## CARBON AND GRAPHITE BURSTING DISKS NOW AVAILABLE IN UK

Powell Duffryn Carbon Products have now introduced for the first time in the UK a range of bursting disk assemblies in carbon and graphite.

A bursting disk provides means by which pressure vessels or other plant are protected from over pressure through the medium of a diaphragm of material weaker than the vessel structure itself. These disks are usually in various metallic materials, often costly, and quite elaborate methods such as hydraulic preforming are adopted to reduce the tendencies inherent in metals to creep or otherwise deform under stress and temperature. The Powell Duffryn design utilizes graphite as a material of disk construction which is immune from such faults.

The complete assembly includes a two-piece holder, disk and vacuum support if required



The design comprises a two-part carbon holder and a high quality replaceable graphite disk. The design of the holder and disk is such that replacement disks are easy to install and moreover location of the disk in the holder is foolproofed by means of the special slotted holder arrangement. The assembly clamps between pipework flanges adjacent to the installation to be protected.

The standard range is available in sizes, 2, 3, 4 and 6 inch bore. Pressures between 5 and 75 psig are offered and bursting accuracy is guaranteed within ± 5 pc of the rated burst pressure.

For disks rated 20 psig or below, vacuum supports of either bar or dial type are available if the possibility of vacuum conditions within the vessel ex-

ists. Working pressures may be up to 75 pc of the nominal burst rating. Special ratings are also available and the Hayes factory has recently produced for the US market, 6 in. disks rated at 1 psig vacuum for the protection of lead lining in process vessels under conditions of negative pressure.

The assemblies are completely resistant to the corrosive effects of a very wide range of contact materials and temperatures up to 160°C. can be tolerated without deterioration of the physical properties of the disk or reduction in bursting accuracy.

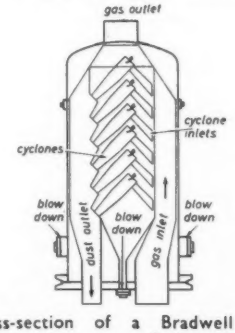
Standard factory control procedure involves the application of 10,000 pressure reversals at 75 pc of burst pressure, followed by full burst pressure which disintegrates the disk within the guaranteed accuracy limits.

Tick **No 131** on reply card

## MANCUNA GAS FILTERS CHOSEN FOR BRADWELL

A contract for eight large capacity bypass filters and eight smaller capacity drier filters for the gas circuits of the Bradwell nuclear power station was recently placed with Mancuna Engineering Ltd by C. A. Parsons Ltd, a member company of the Nuclear Power Plant Co Ltd. Both types of unit use Mancuna's type D450 miniature cyclone (see NUCLEAR POWER, Jan 1958, p 30), the larger unit comprising 22 tubes, the smaller 4.

The cyclone body, cover and inlet are individually shell-moulded in meehanite iron. They are then assembled on ground faces to ensure absolute accuracy. This




Cross-section of a Bradwell unit shows arrangement of the miniature cyclones and the flow directions

ensures that the performance of each tube is identical—a matter of importance since they are used in parallel. Collection efficiencies of 99·87 pc have been reported with velocities of 600 fps.

The Bradwell bypass filter is designed to pass 27 lb/sec of $CO_2$ at 150 psi and 200°C with a pressure loss of 4·5 psi. The pressure vessel of these dust collectors is built in mild steel to BSS :1500 and inspected to Lloyd's Class I or II according to application.

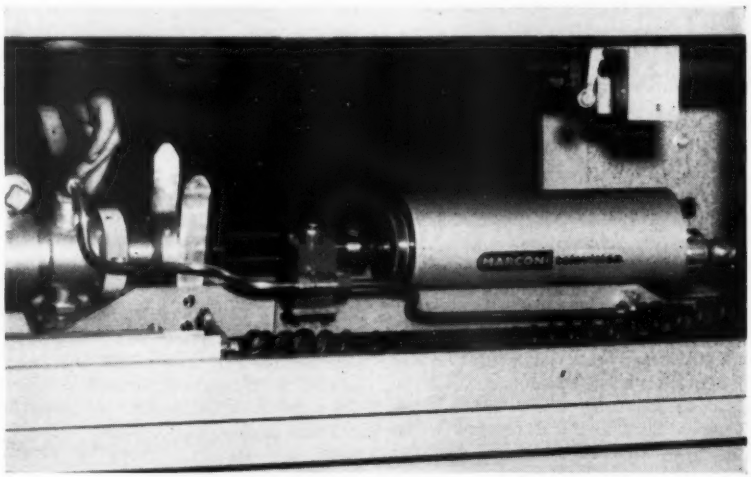
Tick **No 132** on reply card

## LATEST MARCONI TV CAMERA IS ONLY 4 IN. DIA.

Marconi's Wireless Telegraph Company Ltd have in production a new television camera channel for use in closed-circuit applications. The new equipment—Type BD871—is of two-unit construction, comprising the camera proper and its associated control unit. The former is contained in a 4-in. dia. steel cylinder 11 in. long, while the control box measures only 14 by 17 by 8 inches. An English Electric 1-in. *Vidicon* pick-up tube, scanning coils and head amplifier, comprise the camera unit and the encasing cylinder acts as a dustproof container and as a shield against stray magnetic fields. Heat generated is conducted through the casing to be dispersed by radiation. Automatic sensitivity control is fitted which compensates for wide variations of lighting levels without adjustment of the manual controls — a feature which, in practice, enables the equipment to operate completely unattended.

Manual focusing is at the rear of the camera but a remote control unit can be supplied of the same diameter as the camera. The control unit can be installed anywhere up to 1,000 ft away.

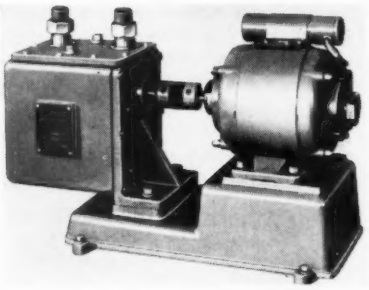
The new camera was first shown at the *Instruments, Electronics and Automation* exhibition at Olympia. On the Foster Instruments' stand it was in use with a periscope for the remote viewing of furnace flame conditions, while Counting Instruments Ltd showed it to illustrate remote viewing of instrument dials. A third camera was seen on the English Electric stand, the picture being seen on a monitor on Marconi's own stand.




Seen at the IEA exhibition, the new camera forms part of a furnace periscope

Tick **No 133** on reply card

## METROVICK ANNOUNCE NEW VACUUM PUMP



The pump is actually two single-stage units on a common shaft running in the same oil tank

The latest addition to the *Metrovac* range of rotary vacuum pumps by Metropolitan-Vickers is the type DR210, comprising two single-stage, vane-type pumps mounted in a single oil tank and driven by a common shaft. The equipment, therefore, has the pumping characteristics of two single-stage pumps with considerable saving in space.

The pump is in good dynamic balance, the centre lines of the sliding vanes in the two rotors being arranged mutually at right angles: vibration is, therefore, greatly reduced. Operational noise has been kept to a minimum by the use of a quiet type of exhaust valve assembly and helical reduction gears.

Like other small rotary pumps in the *Metrovac* series, the DR210 is fitted with an oil baffle, a sight glass, gravity drain plug and a pressure drain connexion on the top cover. For use in situations where a gravity draining of the pump case is impracticable, a special pressure drain attachment can be supplied. The following are brief details:

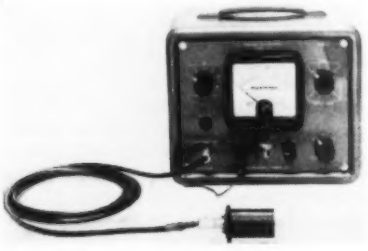
*Displacement*—1 litre/s at 370 rpm rotor speed for each section.
*Ultimate pressure*—At 10 microns Hg by McLeod gauge for each section.
*Pump rotor speed*—370 rpm.
*Motor*—$\frac{1}{3}$ hp a.c. or d.c. supply; high starting torque 1425 rpm.
*Overall dimensions*—Length 21$\frac{1}{2}$ in., width 9$\frac{7}{8}$ in., height 12$\frac{9}{16}$ in.

Tick **No 134** on reply card

## PORTABLE X-RAY DOSEMETER IS BATTERY OPERATED

Electronic Instruments Ltd are marketing a new portable X-ray dosemeter to meet a Ministry of Health requirement. A number of these instruments is being supplied to the Ministry for a national statistical survey of the genetically-significant radiation dose received by the population of England, Scotland and Wales from the use of diagnostic X-rays in hospitals.

The instrument consists of a robust direct-reading battery-operated valve electrometer, mounted complete with ion chamber polarizing supply and a range of input capacitors and resistors in an attractively finished steel case. All the high-insulation input-circuit components,



The instrument is sealed and desiccated to prevent damp from ruining the insulation

including the electrometer valve, are mounted in a lead-lined screening box to reduce errors due to scattered X-rays. Approximately $\frac{3}{32}$ in. of lead is bonded to steel sheet in the construction of this box.

Five input capacitors are fitted to provide dose ranges of 0·45 mr to 150 r full scale in conjunction with a range switch which controls the full-scale voltage sensitivity of the amplifier from 0·45 to 15 V. By use of these two controls, a number of ranges are available.

The polarizing supply is provided by a 300-volt miniature battery of the type used in portable electronic flash equipment for photography. The short circuit current obtainable at the terminals of the instrument is limited to 1 milliamp for safety. The other batteries employed are commonly-available deaf aid types.

Tick **No 135** on reply card

## NEW ORIFICE INTRODUCED BY KENT

George Kent Ltd announce the introduction of the Dall orifice, the latest addition to their range of differential-pressure producing devices, designed and developed by the same hydraulic research team that produced the Dall tube. The Dall orifice is intermediate both in pressure loss and in cost between the square-edged orifice plate and the Dall tube. It is thus particularly suitable for use where pressure recovery is of importance but space or first cost precludes the use of a Dall tube.

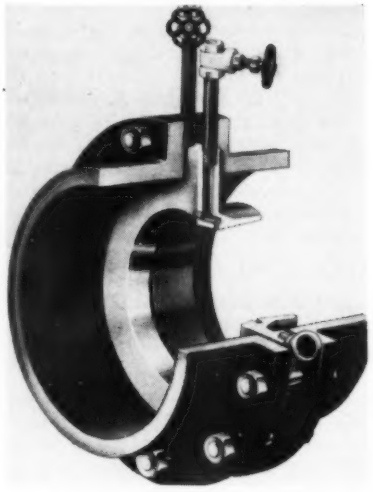
A comparison of the pressure losses incurred by various differential-pressure producers shows that on a medium-velocity installation working with a 100 in.-water-gauge instrument, the pressure loss with a Dall orifice would be only 19 in. w.g., compared with 60 in. w.g. for an ordinary orifice plate or a flow nozzle. With a Dall tube, the loss would be 5 in. w.g.

The Dall orifice is a self-contained, truncated form of Dall tube and has a thickness, where it is clamped between the pipe flanges, of only 1$\frac{1}{8}$ in. The over-all length is 0·3 of the pipe diameter, and the downstream cone simply projects a short way into the downstream pipe.

The design is such that the essential features of the Dall tube have been retained, while the shorter downstream cone gives the desired compromise between cost, space saving and pressure recovery. The pressure tappings are taken out through the rim, and there are drain and/or vent holes through the Dall orifice, thus avoiding the need for separate drains or vents.

Dall orifices are at present available for 6 in. to 24 in. pipes, and are normally cast in gunmetal, but high-grade cast-iron can be used for some applications on 18 in. and larger sizes.

The fluids for which the Dall orifice is suitable are the same as those for the Dall tube—namely, water other than sewage, compressed air, low-pressure



Shorter and cheaper than the Dall Tube, the Dall Orifice gives a much lower head loss than the flat-plate orifice

air, relatively clean and non-corrosive gases, and low-pressure steam such as exhaust steam. The normal installation requirements are as those for other differential-pressure producers.

Tick **No 136** on reply card

## IN BRIEF

**Coextruded metals** Recently developed coextrusion techniques by Nuclear Metals Inc have enabled the fabrication of many combinations of metals in the form of tubing, rods and special shapes. For example, seamless copper tubing, clad inside and outside with zirconium, is one of the products now available for advanced design and specialized purposes.

Tick **No 137** on reply card

Plastic '**poly-grid**' **packings** for forced-draught cooling towers have been designed by Fluor Products Ltd of Los Angeles. They are claimed to give more cooling surface and less pressure drop than standard grid decks. British licencees are Head Wrightson Processes Ltd.

Tick **No 138** on reply card

**BEPO WIGNER RELEASE**

In the May issue (p. 230) D. W. Fry was stated to have advised R. F. Jackson on the test. This should have read T. M. Fry.

## WELDING SYMPOSIUM

Our Buyers' Guide in the May issue should be extended to cover additional entries. Armco Ltd, 75 Grosvenor St, London W1: *electrodes, fluxes, motor generator sets.* English Electric Co Ltd, Queen's House, Kingsway, London, WC2: *electrodes and holders, helmets, rectifiers, transformers.* M. Falk & Co Ltd, Bell St, Reigate, Surrey: *radiography equipment, ultrasonic inspection equipment.* General Electric Co Ltd, Magnet House, Kingsway, London, WC2: *electrode holders, motor generator sets, rectifiers, transformers.* Philips Electrical Co Ltd, Century House, Shaftesbury Avenue, London, WC2: *electrodes and holders, helmets, projection welding machines, radiography equipment, rectifiers, rods, safety equipment, seam welding machines, shielded arc welding equipment, spot welding machines and tips, stud welding machines, submerged arc welding equipment, transformers.*

# Cross-Section by GRACCHUS

THE WRITTEN DISCUSSION of technical papers is often of more interest than the paper itself although of course you can't have one without the other. Just published, is the complete discussion on the Hinton and Moore paper which was read to the Joint Nuclear Marine Propulsion Panel back in November and the impression I gathered then from the spoken discussion that the gas-cooled reactor ship has only very limited applications was reinforced by the written views. Mr L. Nordström of a Swedish shipbuilding firm, for example, produced some most interesting results of a design study his firm had done on the boiling water reactor using primary steam—results which indicated a superiority over other types of reactor. It would, of course, need enriched fuel and so in fact would almost any kind of propulsion reactor. Nearly every speaker made this point but the authors were completely unforthcoming as to how or when it would be available. I was amused to read a comment on this by Mr M. C. Houston, who pointed out that the running of six million television sets taking 100 watts each would need two power stations of 350MW each. Mr Houston's plan was to have an hour's embargo on television a day during which the power would be used to produce either U-235 or $D_2O$. Ingenious but impracticable, I fear, since both these plants take many weeks of continuous operation to reach steady conditions. Incidentally, I gather that, contrary to widespread assumptions, the Hinton and Moore paper does not represent official thinking but is simply the views of the authors.

DUE to a basic similarity in name, I suppose, NUCLEAR POWER receives a great deal of mail wrongly addressed and the editor tells me he has been snowed under recently with letters bearing American stamps and addressed merely to Nuclear Power, London, or even to Nuclear Power, England. These are invariably applications for jobs with the Nuclear Power Plant Co and, this is the point, they all want to work in Italy. Truck drivers, welders, electricians, sheet metal workers and even clerks—all seem to be attracted by the thought of a job in sunny Southern Italy. What happens to these applications? I understand they are all told that industrial staff is recruited in Italy and given the correct address. I wouldn't rate their chances very high since one reason for building the SIMEA station in the South instead of in the North, as was originally intended, is to bring employment to a depressed area.

IN THESE DAYS of hectic technical and scientific advance one of the biggest problems is that of assimilating and disseminating information—information which is nearly always in the form of the written word. Many research workers in fact find the actual performance of their job much easier than reading about it, let alone writing about it. Gone forever are the spacious days when the workers in the field were few, when days were long, when the Darwins, the Huxleys, the Eddingtons and the Jeans's had time to write up their work in a form which was somewhat more than a mere scientific report. Science has become so complicated and expensive that it is now a matter, not of the brilliant individual, but rather a case of high-powered teamwork conducted on the lines of a business or even a military operation. Furthermore the young scientist of today is not endowed as his Victorian ancestor was for proficiency in language having usually begun to slough off traces of a humanistic culture towards the end of his school career. Exceptions there are, but on the whole the scientist is often ill-equipped to put his case over.

I was interested therefore to see that the City and Guilds of London Institute has published regulations and a syllabus for a new course and examinations in technical authorship. This of course goes far beyond anything that the working scientist or engineer needs for the occasional articles or paper and is intended rather for the full-time author who has to deal with illustrators, printers and publishers. Nevertheless, parts of the syllabus might well form the basis of a much shorter course for occasional writers and I'm sure if this were offered at convenient centres it would prove popular. One thing that did strike me however was the fact that among the 29 members of the Advisory Committee, I failed to detect the name of a single professional journalist. Admittedly, technical authorship in the sense intended is some way from journalism but I'd have thought that at least one man whose job it is to write magazines could perhaps have contributed a few ideas. Every one of us must at some time or other have had the feeling on reading a difficult technical article—or even a car instruction book!—that although we couldn't quite understand it, it was probably very good for that precise reason. Often this truth is the exact opposite: we didn't understand it, simply because it was a very bad piece of writing. I don't think journalists set themselves up as authorities on current English usage but at least they are writing it for sale every day and have to attain a degree of proficiency in expressing ideas with as little fuss as possible.

IT IS NOT, I think, generally realized just how much canning there is in a gas-cooled reactor and with materials such as beryllium in the offing this could amount to a major item of expense. A simple slide-rule calculation on the Calder Hall finned magnesium can shows that the volume of this is very nearly equal to the volume of uranium. Metals of course are sold by weight, which rather improves the picture. Furthermore, in advanced reactors the finning is likely to be rudimentary. But even so, it is clear the cost factor is a major one.

**On Record**

*I predict . . . Admiral Lewis Strauss, chairman of Washington's Atomic Energy Commission will be out of his job by August.* Sefton Delmer, 'Daily Express,' May 2.

*Perhaps secondary schools are already producing so many scientists that in five years' time somebody will be calling a conference to discuss how we can get more artists.* T. R. Weaver, Under-Secretary in charge schools branch, Ministry of Education.

*Government support for the training of technicians may be necessary if the electronics industry is to meet the challenge of the American industry which is undoubtedly subsidized by the Government's provision of special facilities for training.* G. A. Marriott, President, British Institution of Radio Engineers.

*Our fundamental research centre has recently been moved to new headquarters selected to provide an atmosphere more conducive to the quiet thought and intense work required for the advance of creative pure science.* George M. Bunker, president Martin Co, USA.

*Harnessing of thermonuclear fusion will take place much more quickly than our scientists are willing to predict in public.* Lord Chandos, at BEDA lunch.

# INDUSTRIAL NEWSDESK

## Nuclear ships: NPPC moves in

A joint venture for the design and construction of nuclear powered ships has been announced by the Nuclear Power Plant Co and Swan, Hunter and Wigham Richardson Ltd, the shipbuilders. In addition to passenger and cargo ships this company has considerable experience in the construction of large oil tankers, having recently completed one of 38,000 tons, and will soon be starting on the construction of 65,000 ton projects.

It is the fourth UK shipbuilder to make cooperative arrangements for studying nuclear ship propulsion. The others are Cammell Laird, with Babcock & Wilcox, Vickers with Foster Wheeler and Rolls Royce, and John Brown, with Hawker Siddeley. Two other companies also working in the field are Mitchell Engineering Ltd and Richardsons Westgarth Atomic Ltd.

## Philips and Mullard reorganize

A new company—Research and Control Instruments Ltd—has been formed to act as sole distributors in the UK for the electronic instruments and scientific equipment hitherto marketed by Philips Electrical Ltd (Research and Control Instruments Division). Director and General Manager is R. H. Cooke, and operations started on May 1 from Instrument House, 207 King's Cross Road, London, WC1 (*Tel*: Terminus 8444). A specialized sales and service organization will be established throughout the country and full responsibility will be assumed for the maintenance of existing Philips equipment. Field staff will be supported from a new service department and stores located at 49 Temperley Road, London SW12 (*Tel*: Battersea 9166). The company will in addition become the sole distributors in Great Britain for the industrial X-ray equipment manufactured by C. H. F. Müller AG of Hamburg and for Norelco (US) X-ray diffraction and spectrographic equipment.

New to the British market and also to be handled by the company will be the electronic instruments made by Elektro-Spezial AG of Hamburg.

General Manager Cooke is well known in instrument circles. He played a prominent part in organizing the British exhibit at the first 'Atoms for Peace' conference in Geneva and serves on the committee of the nucleonics section of the Scientific Instrument Manufacturers' Association (SIMA). Having been associated for some time with non-destructive testing in industry, he is also a founder member of the Society of Non-destructive Testing (SONDE).

Research and Control Instruments have taken over the sale and servicing of Mullard electronic measuring instruments and electro-chemical apparatus in the UK. Overseas sales of these products will be handled direct by Mullard Equipment Ltd, as will the home and overseas sales of Mullard's other products such as telecommunications equipment, linear accelerators, industrial control systems and high power ultrasonic generators and transducers. Mullard low power ultrasonic tinning, cleaning and machine equipment will henceforth be distributed in the UK by Kerry's (Ultrasonics) Ltd only.

COOKE
Will form electronics sales and service organization

Another change is the establishment of a new product division by Mullards for semi-conductors, including transistors. Managed by G. A. Gilbert it will have two sections; one for commercial activities and coordination of semi-conductor product matters generally will be headed by P. A. L. Harris; in charge of the other, which will be responsible for technical advisory services in the government and industrial fields, will be G. D. Grimsdell.

## Isopad makes largest heater

An electric heating mantle for testing 60 in. valves bound for an atomic power station has recently been ordered from Isopad Ltd. This 14 ft-high, 15 ft-wide *Isomantle* will heat the valves to 750°F while they are tested at pressures of up to 280 psi and will be the biggest of its kind ever made. Construction will be in rail-mounted sections so that the heater can easily be brought up to the valves. It is the latest of a considerable amount of special equipment designed by the company to deal with problems peculiar to atomic energy. Heating units were developed for filters in process gas separation plant and have been operating for five years at Capenhurst with no maintenance except for mechanical damage. Large quantities of the company's standard laboratory heaters are used at AERE, Harwell, and at AWRE, Aldermaston.

The heaters employ specially woven glass cloth which can withstand up to 350°C or pure quartz cloth for loadings beyond this temperature. Using the latter material satisfactory tests have been carried out at temperatures as high as 900°C at AWRE. Another application is the regeneration at elevated temperatures of rare gases which have been used in processes employing radioactive materials. For this work the jackets are provided with cut-outs on meeting faces for inlet and outlet gas connexions and thermocouple pockets. Many of them have run continuously for nearly two years. Pipelines carrying process gas are heated by flexible electric heating tapes to keep the gas at the correct temperature. A pointer to future developments is the completion of special units made in cooperation with the design engineers of atomic establishments and Royal Ordnance Factory design departments.

## Another Hinkley order for CEGB

A £980,000 contract has been awarded by the Central Electricity Generating Board to The English Electric Co Ltd for a 15 circuit duplicate busbar switching station for Hinkley Point power station in Somerset. The order cover the generator, feeder, station transformer and bus coupler circuits, as well as fourteen 7500 MVA air blast circuit breakers, with associated control and relay panels. Equipment for the 275 kV switchgear will be made at English Electric's Stafford Works.

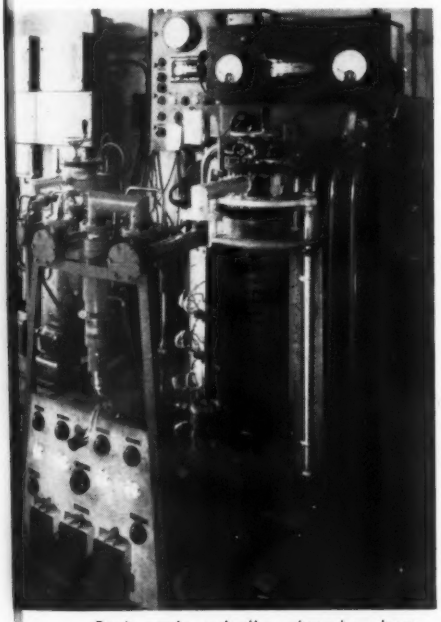
## MetVick expands nuclear research

A laboratory for metallurgical study of support rigs and both prototype and used fuel elements has gone into commission at the Wythenshawe works of the Metropolitan-Vickers Electrical Co Ltd. Contained in a recently completed building, the laboratory incorporates extensive provisions for elimination of health hazards. It will be an important addition to the company's activities in the atomic energy field, following the special laboratory equipped last year for the fabrication and working of beryllium products. This contains facilities for the safe handling of beryllium powder, machining of the solid metal and preparation and metallographical exam-

ination of small samples. Hot-working facilities, welding facilities and vacuum furnaces are also available in the toxic area.

More details of the company's metallurgical research programme are now released. Experimental studies have been made on the corrosion behaviour of binary and ternary alloys of zirconium under attack from carbon dioxide at 500°C and 150 psi pressure and other metals examined include mild steel, beryllium, magnesium and uranium. Heat treatment and short time mechanical tests have been carried out on some of the materials and the results applied in the design of reactor core components. Fabrication properties explored experimentally include deep drawing, forging and cold rolling.

A 2¼ in. dia consumable electrode furnace has been used to investigate methods of vacuum arc melting zirconium alloys and techniques of making alloying additions have been developed. Work on production by the iodide process has continued to assess its usefulness as a method of reclaiming scrap zirconium. Both crude and alloy metal



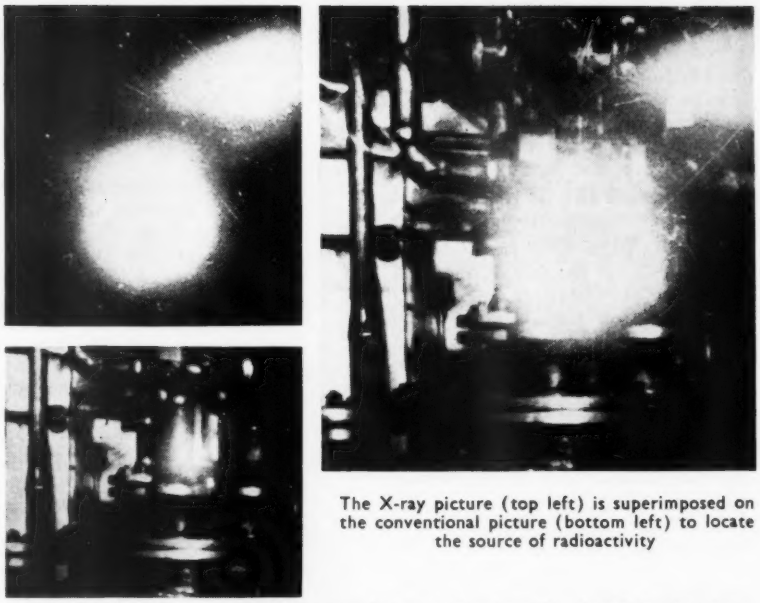
Both crude and alloy zirconium have been cycled through this Van Arkel plant to assess its usefulness for reclaiming scrap

has been cycled through the equipment and many batches of sponge, of commercial grades and of scrap have been converted.

## Hinkley group sets up company

In future the administration of the contract for the nuclear power station at Hinkley Point will be carried out by a new company, the English Electric, Babcock & Wilcox and Taylor Woodrow Atomic Power Construction Co Ltd. The work will be handled by the three companies of the group under sub-contracts with the new company. Directors are H. G. Nelson (English Electric), H. McNeil (Babcock & Wilcox) and F. Taylor (Taylor Woodrow Construction) and headquarters are at Whetstone.

A spokesman for the company emphasized that little will be altered in practice as the three constituent companies have worked closely together in the past, and the move seems to be mainly a tidying up operation. Any future orders for nuclear stations will also be administered by the new company.



The X-ray picture (top left) is superimposed on the conventional picture (bottom left) to locate the source of radioactivity

A lead and uranium 'pin-hole' camera has been developed in the US for locating sources of radioactive contamination too hot for detection instruments. Weighing 29 lb it is about the size of a box camera, and simultaneously takes pictures on conventional film and records radiation on X-ray film. The photographic record can be made in minutes. Designed by an engineer at the US General Electric Co it is in use at Knolls Atomic Power Laboratory

## Joint reactor instrument service

A joint service for the contracting, engineering and manufacture of over-all instrumentation schemes for both power and research reactors is announced by Ekco Electronics Ltd and George Kent Ltd. Their individual or combined resources will be available for contracts of all sizes and enquiries may be addressed to either company. This move follows close cooperation in the supply of complete instrumentation for four heavy water research reactors. Kent are producing the physical instrumentation for various reactors, heat exchangers and turbines as well as recorders for the nucleonic side. Ekco manufactures an extensive range of nucleonic control and health instrumentation and the joint coverage of the two extends over most of the instrument sphere.

## In brief

The annual report of **Lloyd's Register** of shipping for 1957 warns that the time must come, if it has not already arrived, when increasing the size and shell thickness of a normal carbon steel reactor vessel to give more power will no longer be practicable.

The **Mitchell** Construction Co, main civil engineering contractors for Chapel Cross has become a limited company with D. D. Morrell as managing director.

Automatic Telephone and Electric, English Electric, and Ericsson Telephones announce the formation of a jointly owned company for the development and manufacture of **transistors** and other semi-conductor devices. The company, to be known as Associated Transistors, has an authorized capital of £750,000, and is constructing a factory at Ruislip, Midd, of some 55,000 sq ft.

A **course** on the control and instrumentation of reactors is to be held at the Harwell Reactor School from 6 to 11 October. Further details from the Principal, Reactor School.

The first order for a **television** nuclear reactor camera has been placed with Pye Ltd. It will be used at Bradwell to help engineers inspect reactor interiors.

The Mullard Company has made an offer to Oxford University of £50,000 payable over a ten-year period towards the cost of the **new college.**

# *They said...*

*points from papers, speeches, conferences*

## Recycling can cut fuel by 66 pc

Spent fuel element recycling should reduce by a factor of three the natural uranium feed for the four 'first-round' UK nuclear power stations and any similar ones sold overseas. This was stated by Sir John Cockcroft on May 17 at Brussels when delivering a speech on 'Nuclear energy, the power of the future' to the British Electrical Conference held in support of the industry's collective exhibit. He disclosed that this was the figure adopted by the Atomic Energy Authority for calculating its spent fuel repurchase estimate of not less than £5000 per tonne. 'We may on the other hand,' he added, 'use the plutonium obtained from spent fuel elements in small pressurized water or organic liquid moderated reactors for use in propulsion units, so there is a challenge to designers here.'

## Exploiting UK isotope lead

A question now being put to industrial users of radioisotopes is 'How much do they save you?' The enquiry, started recently, is broken down under such headings as savings in labour costs, speed of production, and expenditure on gauging and inspection. This was revealed at the FBI Conference on Nuclear Energy at Eastbourne by W. G. Busbridge, Principal Scientific Officer of the Atomic Energy Authority's Isotope Division. Considerable sums of money have been saved in the US by industrial applications of isotopes—$M406 a year was the figure named recently by Dr Libby of the Atomic Energy Commission—and Mr Busbridge expressed the hope that the survey will point to fresh extensions for research and industry in this country.

## New method of reactor study

At the present time the analogue computer is widely used to study the kinetic behaviour of nuclear reactors, but it appears that the new reactor transfer function analyser developed at AERE Harwell may prove a powerful competitor. At a recent meeting of the British Institution of Radio Engineers a paper on the analyser was delivered by R. J. Cox, head of the reactor instrumentation group at Harwell. The paper was prepared in collaboration with D. Harrison, also from the reactor instrumentation group, and R. B. Stephens of Mullard Equipment Ltd. Constructed for use with the fast reactor at Dounreay, the analyser was demonstrated at the meeting using a reactor simulator. The method employed is that of treating the nuclear reactor as a four-terminal network with feedback, in which the output response to an input disturbance is measured and analysed.

In its first form the system makes use of a reactivity disturbance by movement of a control member to produce a response measured in terms of neutron flux with an ionization chamber but the

R. J. COX
Device can predict reactor behaviour at high power

method can be extended to tackle a wider range of problems involving disturbance and measurement of other parameters, say the authors. One example would be temperature, using thermocouples. The analyser is also a useful tool for the determination of the magnitude of certain physical constants which are difficult to obtain by other means. Another application would be the prediction of the behaviour of a reactor at high power levels from low power measurements.

## Rivalry may hinder ship licensing

If a nuclear ship gets into difficulties at sea and seeks haven in the nearest port, is it to be accepted or rejected? There are many potential headaches for port authorities where the safety of handling nuclear ships is concerned. The fire record of ships in port, for example, is very frightening from that point of view. These points were raised by P. T. Fletcher, of the AEA Industrial Group in a speech to the Dock and Harbour Authorities Association, the text of which has now been released by the Authority.

Operating skill is of paramount importance, and he visualized specialized training, looking forward to the possibility of a new extra chief's ticket in ten or fifteen years' time. On the other side of the picture must be considered the responsibility of port authorities anxious to handle nuclear traffic. One thing they must provide is a complete and immediate first aid service.

Insurance for reactors in transport generally was specifically excluded from the Minister of Power's proposal that a Bill be presented to Parliament covering the licensing of reactors, but international licensing rules will certainly become necessary. One of the real difficulties to be overcome will be the reluctance of manufacturers to permit the close individual study of each reactor which will be needed. The information required will go beyond the scope of ordinary scientific exchanges 'to developments of which both countries and their business concerns are naturally jealous.' Our insurance interests are working quite determinedly on being able to meet some of the commercial problems arising from international nuclear business. 'Until we are able to measure risks against quotations for insurance I think we shall be in a difficult position in developing nuclear power for the merchant service' he said.

The carriage of radioactive materials will present some problems, at any rate where highly enriched fuels are concerned. If the UK exports nuclear reactors each one would involve the transport of one or two containers weighing between 40 and 50 tons containing about a ton of spent fuel elements each week. Work is going on now on the problem of design and movement.

## Staff problems at Dounreay

The nuclear programme in Scotland is already emphasizing the scarcity of skilled instrument technicians, a problem made acute by the wider use of instrumentation in industry. Speaking at the Glasgow dinner of the Scottish section of The British Institution of Radio Engineers Major General Joslin, previously works general manager at Dounreay, said that they had some 3500 instruments in use there and had not the trained staff to maintain and handle them. They had therefore been obliged to meet the situation by upgrading and training fitters and electricians to give them the necessary finesse into the handling of instrumentation work.

# Book Reviews

## A wealth of material

**Kempe's Engineers Year-book for 1958**—63rd edition Editor C. E. Prockter London 1958 : Morgan Bros. 3000 pp 82s. 6d.

Sixty-three editions of 'Kempe's' have provided the worker on engineering and allied subjects with the essential information and data required to solve many of his problems. If there be any reader of NUCLEAR POWER who is not already familiar with the two chunky red volumes he will find in them a wealth of material ranging from tables of mathematical functions, hydraulics, electrics and civil engineering through the properties of materials and metallurgy to detailed descriptions of almost every conceivable kind of machine.

To those long familiar with the work, the impressiveness lies not in the wide and detailed coverage, for these are plainly the fruits of its long and continuous history, but in the way it keeps up to date. Typical examples of this are the excellent account of powder metallurgical processes and the modern lists of specifications in metallurgy, the up to date list of aircraft types including the Viscount 800, and the section on disk brakes for automobiles. A diligent search through the book for likely omissions was rewarded only by the absence of any reference to high top pressure blast furnaces.

Perhaps the most serious fault is that the binding is not strong enough to stand up to the hard work that the excellence of the book as a work of reference will impose. The section on Atomic Energy is still disappointing. Some attempt has been made to improve it and bring it up to date but it is still not up to the standard of the rest of the book. Instead of a detailed account of power generation by fission and the different types of reactors, the section confines itself to generalities and comparisons of British and American effort. This must surely be of little interest to an engineer who would be more interested in size and thickness of pressure vessels, temperature and pressure of coolant, heat transfer surface rating and fuel material. The bibliography of this section also suffers in comparison with that of the others.

Many other sections have been rewritten, notably those on welding, corrosion, diecasting, machine tools, aerodynamics and aircraft propulsion, public cleansing and electronic engineering and many other alterations and additions made.

**L. M. Wyatt**

## A good introduction

**The cosmic radiation** J. E. Hooper and M. Scharff, London 1957, Methuen 176 pp Price 12s 6d

In many fields of modern physics, knowledge is expanding so rapidly that writing a text-book has become extremely difficult and very discouraging. This is particularly so in the field of cosmic radiation, where the recent examples of text-books have been out of date as soon as they were on sale. Indeed, the more care is taken to present the latest view, the more conspicuously is it dated when the book appears.

This pitfall has been mainly avoided in this admirable little book by presenting only what has survived at least a few years. The authors state that the book is based on a course of lectures, presumably to undergraduates, or students in their first year of research. The first quarter of the book describes the experimental techniques and the main features of ionizing collisions upon which nearly all cosmic ray experiments ultimately depend. A brief chapter discusses both the geomagnetic effects and the charge spectrum of the primary radiation. Two succeeding chapters are devoted to high energy nuclear interactions and electromagnetic processes, and cover the ground very adequately. A short chapter gives an account of the unstable mesons and hyperons, mostly discovered in cosmic radiation, but now better considered as a study of their own with the aid of high energy accelerators. The remainder of the book describes the energy balance in the atmosphere, and the effects observed underground.

It is perhaps wise of the authors to have omitted almost entirely any reference to the very involved subject of the time variations of cosmic ray intensity, since few of these have received an unambiguous interpretation, but there is now enough information about extensive air showers to warrant more than the bare mention which they receive here. Apart from this omission, the book can be recommended as a good introduction to the subject.

**T. E. Cranshaw**

## A laboratory manual

**Radioisotope Laboratory Techniques** R. A. Faires and B. H. Parkes 240 pp London : Newnes Price 25s.

Many industrial applications of isotopes—thickness gauging, level control and static elimination for example—need practically no specialized knowledge for their safe and efficient operation: one simply buys the completely productionized equipment from the manufacturer and calls him in only if it goes wrong. On the other hand there are many industrial research applications, such as wear studies and tracing techniques, for which sound theoretical training coupled with good practical laboratory experience is essential. For workers in these fields—and of course those using isotopes in biological, medical and agricultural work—the Head of the Harwell Isotope School and a colleague have prepared what they describe as 'a manual for the man in the laboratory.' No one, least of all the authors one imagines, would expect anyone to start up a radioactive laboratory on the sole basis of this—or of any other book for that matter. The essential of practical experience is that it is handed on personally. Nevertheless, Mr Faires and Mr Parkes have done a useful job in putting—as far as one can do it—these things on paper.

The contents are roughly divided into four sections: basic considerations of nuclear physics, isotope production and radiological protection; laboratory design, hazard control and waste disposal; methods of detection and measurement including statistics and choice of equipment; radioisotope techniques and applications and feasibility. There are also included some useful appendices.

Faults there are. The chapter on the electronics is really too fragmentary to be of much use and throughout there is too much casual introduction of new terms without explanation. This could be annoying to those approaching the subject for the first time. The book is well produced and its low price is noteworthy.

**T.A.J.**

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**Books on nuclear engineering.** Blackwell's, the well-known booksellers of Broad St, Oxford, have issued a useful catalogue of books on nuclear engineering.

**Economia Internazionale delle Fonti di Energia** is a bi-monthly review devoted to studies in the field of world energy resources and utilization. Directed by a committee under Prof Giuseppe Pella, it is edited and published for the Luigi Bocconi Commercial University by Dr A. G. Giuffrè, Via Solferino 19, Milan.

# NAMES IN THE NEWS

Metropolitan-Vickers Electrical Co Ltd have appointed **Mr L. H. J. Phillips** to be assistant commercial manager. Mr Phillips is succeeded as sales manager, electronics department by **Mr A. G. Barton,** who was formerly sales engineer.

**Mr D. W. Payn,** general manager and secretary to the Lead Development Association has recently returned from a short visit to the United States and Canada.

Tube Investments Ltd announce that **Mr A. J. S. Aston** and **Mr R. D. Young** have been appointed to the board after many years with the Group in senior executive capacities.

**Mr L. W. D. Sharp,** newly appointed chief engineer of the Ilford Components Group of Plessey, was recently presented with a cheque by the public relations committee of The Radio Industry Council for his article *Components for printed circuits* which was published in 1957.

**Dr L. L. Ross** has been appointed deputy managing director of Elliott Brothers (London) Ltd. **Rear-Admiral Sir Alexander D. McGlashan** and **Mr. J. E. O'Breen** have been appointed directors of the company.

Airmec managing director **Dr J. C. Simmonds** left England on a visit to Switzerland recently to explore the market for Airmec industrial electronic equipment.

The Vitro Corporation of America have elected **Mr Charles J. Potter** to their board of directors. Mr Potter is president of the Rochester & Pittsburgh Coal Company.

**Mr S. G. P. de Lange** has relinquished his responsibilities as commercial manager of the industrial products division of Philips Electrical Ltd, and is now appointed advisor to the company and coordinator in all matters affecting industrial products. He is succeeded as commercial manager by **Mr C. W. V. Davis,** formerly manager of the filtration department.

Following the death of Mr F. Briggs, secretary of William Jessop & Sons Ltd and J. J. Saville & Co Ltd, **Mr D. Milne** has been appointed secretary and **Mr J. V. Gregory** assistant secretary of the companies.

Vickers Ltd have made the following changes in Group organization. **Sir Thomas R. Merton,** having reached retirement age will vacate his seat on the board at the AGM on June 2. **Sir Sam H. Brown** has been appointed an additional director. **Mr J. H. Robbie** has been appointed a director of Vickers-Armstrongs Ltd, he is succeeded as commercial director of Vickers-Armstrongs (Engineers) Ltd by **Mr E. P. Tomlinson. Mr A. Lawrence Cooper** is appointed secretary of Vickers Ltd in succession to Mr Tomlinson and **Mr J. McLean** is appointed deputy secretary. **Mr T. C. Raymond** is appointed a special director of Vickers-Armstrongs Ltd.

**Mr H. S. Davidson,** transmission engineer of the Midlands Division of the CEGB has been appointed divisional controller of the South Western Division of the Board.

**Mr W. Harrison Faulkner,** jr. has been elected vice president for engineering and development of the American firm of Tracerlab Inc.

The Royal Society have elected **Professor Sisir Kumar Mitra** a fellow. Professor Mitra is professor of physics and director of the Institute of Radio Physics and Electronics of the University of Calcutta, and is chairman of the Calcutta section of The British Institution of Radio Engineers.

**Mr E. J. G. Wayman,** a director of Rocol Ltd, manufacturers of special lubricants, is at present on a 9-week tour of Africa on behalf of the company.

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The death occurred on April 27 of **Mr P. H. Muirhead,** CBE. Until his retirement in January, Mr Muirhead was managing director of Vickers-Armstrongs (Engineers) Ltd, he was also a director of Vickers Ltd and of other companies. Mr Muirhead was 53.

C. W. V. DAVIS

S. G. P. de LANGE

H. S. DAVIDSON

# CATALOGUES AND BULLETINS

Intermit Ltd, European licensees of the *Far-Air* and *Rotonamic* air cleaning equipment have issued a free loose-leaf catalogue describing the comprehensive **range of filters** for conditioned air, engine intakes and other applications. Working efficiencies are shown on graphs.

Tick **No 121** on reply card

Welding of titanium is the subject of the latest Jessop information sheet No. M783.

Tick **No 122** on reply card

Recent literature from Klaxon Ltd describes their very comprehensive **range of motors,** geared and otherwise.

Tick **No 123** on reply card

**Glove-box filter,** developed particularly at the request of Harwell, is given a full page of description in a leaflet about special purpose air filters from Vokes Ltd.

Tick **No 124** on reply card

**General Radiological Ltd** have sheafs of leaflets available covering multifarious products such as remote handling equipment, a combined beta and gamma ionization chamber and various types of ratemeter.

Tick **No 125** on reply card

Remote handling equipment for atomic research work, electronic control gear, testing apparatus and special purpose machinery are described in a **new brochure** from the Ayling Nuclear Equipment Company.

Tick **No 126** on reply card

**180-page welding** data book published by Eutectic Welding Alloys Co Ltd describes simplified welding procedures for application to all metals at reduced temperatures, and contains useful information on maintenance, repair, and fabrication of all metals. It is available free.

Tick **No 127** on reply card

*Witch* **pipe hangers** and supports manufactured by Carpenter & Paterson Ltd are detailed in a 100-page book now available. Most of the hundreds of varieties obtainable are illustrated.

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Tick **No 60** on reply card for further details

# How to select the right alloy

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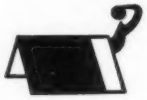

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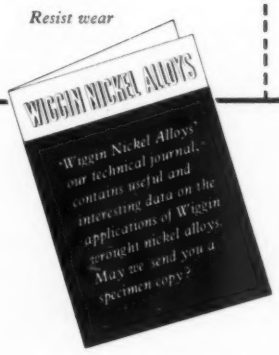
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# Research Reports

*The following reports have been made available to the public by the United Kingdom Atomic Energy Authority. They may be borrowed or photocopies obtained from the Science Library, London, Department of Industrial and Forensic Science, Belfast, the Mitchell Library, Glasgow, and the Central Libraries at Acton, Birmingham, Bristol, Kingston-upon-Hull, Leeds, Liverpool, Manchester, Newcastle-upon-Tyne and Sheffield. They are also deposited in the Copyright Libraries (i.e. British Museum; University Library, Cambridge; Radcliffe Science Library, Oxford; National Library of Scotland, Edinburgh; National Library of Wales, Aberystwyth) and in the Patent Office Library. Reports marked* may be purchased from Her Majesty's Stationery Office.*

*Reports are also available in the United States, from the USAEC depository libraries, a list of which will be found in NUCLEAR SCIENCE ABSTRACTS. Reports for sale may be purchased in the United States from: Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.*

## AERE Harwell

Measurement of diffusion length in a large block of graphite. *M. E. Clifford.* (Jan 7, 1949. 9 pp) AERE T/R 287 2s*

Macrostructural examination of case uranium bars. *B. W. Mott, H. R. Haines.* (April 1950. 13 pp) AERE M/R 509 2s 6d*

The thermal neutron cross sections of Hf, Br, V, Se, Mo and Bi. *P. A. Egelstaff.* (April 16, 1953. 31 pp) AERE N/R 1147 4s*

The diffusion of argon in silver with an appendix on the diffusion of rare gases in uranium. *A. D. LeClaire, A. H. Rowe.* (June 24, 1954. 34 pp) AERE M/R 1417 5s*

A method for the determination of radiocalcium and radiostrontium in effluent. *B. A. Loveridge.* (March 1956. 24 pp) AERE C/R 1902 4s*

The semi-quantitative determination of traces of sodium, potassium and magnesium in bismuth and bismuth-uranium alloys. *R. J. Webb.* (Dec 1957. 7 pp) AERE C/R 2116 1s 9d*

The viscosity plate thrust bearing. *D. V. Wordsworth.* (Oct 1952. 52 pp) AERE E/R 2217 8s*

The adsorption of water on pile graphite. *C. C. Horton, L. E. J. Roberts.* (July 1950. 23 pp) AERE C/R 2219 4s*

The removal of fission products from solution with a precipitator-column treatment. Part I. Laboratory trials. *K. G. Seedhouse, J. Monahan, G. Wallis.* (1958. 32 pp) AERE ES/R 2220 5s*

The preparation, properties and alloying behaviour of thorium. *J. R. Murray.* (June 25, 1957. 35 pp) AERE M/R 2242 5s 6d*

Fission product separation by ion-exchange. *F. Morgan, M. L. Sizeland.* (1952. 18 pp) AERE C/R 2277 3s*

On the image field in a cut wall. *W. B. Thompson.* (Sept 1957. 23 pp) AERE T/R 2300 3s 6d*

The analysis of thorium-boron and uranium-boron alloys. *G. A. Barnett, G. W. C. Milner.* (Dec 1957. 15 pp) AERE C/R 2307 2s 6d*

The radial equation for spiral ridge accelerators. *D. Morgan.* (Nov 1957. 34 pp) AERE T/R 2361 5s*

The determination of tributyl phosphate in kerosene solutions. *A. J. Fudge, G. C. Hutton.* (May 1954. 19 pp) AERE C/R 2384 3s*

Properties of hexone in relation to its use for uranyl nitrate extraction. *D. Bradley.* (Dec 1953. 29 pp) AERE CE/R 2408 4s 6d*

Preparation of uranium tetrachloride. *E. R. Harrison.* (1951. 11pp) AERE GP/R 2409 2s 6d*

The chemistry of ruthenium with reference to the plutonium separation process. Part 4. The sulphide treatment for ruthenium in the uranium stream. *G. L. Miles, F. S. Martin, W. T. Appleton, J. Herrington.* (Nov 1950. 16 pp) AERE C/R 2413 3s*

Vertical motion in spiral-ridged accelerators. *J. W. Burren.* (Dec. 1957. 19 pp) AERE T/R 2423 3s 6d*

A survey of data and information on molten sodium hydroxide relevant to its application as a reactor medium. *J. N. Gregory, N. Hodge.* (Nov 1957. 23 pp) AERE C/R 2439 4s*

The preparation of anhydrous plutonium trichloride. *B. R. Harder, F. Hudswell, K. L. Wilkinson.* (Dec 1957. 5 pp) AERE C/R 2445

The performance of a pulse amplitude analyser type 1414A for routine urine analysis. *W. P. Hutchinson.* (Nov 1957. 13 pp) AERE MED/R 2455 2s 6d*

Tracer experiments on technetium. *F. Morgan, M. L. Sizeland.* (Dec 21, 1950. 13 pp) AERE C/M 96 2s 6d*

A general method for the rapid determination of total strong acid anion in solution. *M. J. Cabell.* (July 29, 1952. 8 pp) AERE C/M 155 1s 6d*

Organo-uranium compounds. *A. E. Comyns.* (Sept 1955. 9 pp) AERE C/M 258 1s 9d*

The determination of plutonium as a minor constituent in alloys with lead, tin and bismuth. *K. W. Brooke, D. H. F. Atkins, E. N. Jenkins.* (Dec 1957. 6 pp) AERE C/M 336 1s 9d*

Heat conduction in charcoal columns. *E. Glueckauf, R. E. Watts.* (Jan 1958. 6 pp) AERE C/M 337

Notes on the toxicology of dibromethane and tetrabromethane. *F. M. Turner.* (Nov 1957. 8 pp) AERE MED/M 21

Preliminary fabrication studies on U-Th-Be fuel elements. *W. J. Wright.* (Oct 1957. 10 pp) AERE M/M 179

The examination of uranium-molybdenum and uranium-niobium alloys for irradiation tests. *J. R. Murray, F. L. Jagger.* (Dec 1957. 14 pp) AERE M/M 182

Slow neutron resonance analysis with a poor resolution spectrometer. Part 1. Thin samples. *P. A. Egelstaff.* (Feb 19, 1953. 8 pp) AERE N/M 57 1s. 9d*

The thermal neutron cross-section of boron. *P. A. Egelstaff.* (Nov 3, 1953. 10 pp) AERE N/M 62 1s 3d*

Some studies of the reaction between sodium and bismuth. *R. I. Hawes.* (Sept 1957. 13 pp) AERE R/M 138

Approach to criticality: refinements in the calculations. *O. Buneman.* (June 11, 1948) AERE T/M 5 1s 9d*

Calculation of the thermal fine structure in a pile with hollow rods by the spherical harmonics method. *M. E. Mandl.* (March 16, 1951. 11 pp) AERE T/M 46 2s*

Calculations on the rate of swelling of gas bubbles in uranium. *A. J. E. Foreman.* (March 1956. 15 pp) AERE T/M 134 3s*

Injection into the 7 GeV synchrotron. *M. Bell.* (Jan 1956. 19 pp) AERE T/M 155

Homopolar generators and liquid metal brushes. A bibliography. *M. Greenhill, N. Skeats.* (1957. 9 pp) AERE Inf/Bib 92 1s 9d*

Molecular sieves. A literature survey. *B. J. Wilson.* (Dec 1957. 5 pp) AERE Inf/Bib 116 1s 2d*

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Measurement of liquid-metal levels by the effect of eddy currents on an inductance. *D. F. Davidson.* (Dec 1957. 10 pp) IGR R/CA 255

Nuclear power and reactor engineering: selected and annotated references. *J. C. Hartas.* (Feb 1958. 17 pp) IGRL IB/R 6 3s*

## JUNE DIARY

MONDAY 2-THURSDAY 5
LOS ANGELES 4th Annual reunion of the American Nuclear Society

MONDAY 2-FRIDAY 6
SYDNEY Symposium on the peaceful uses of atomic energy at the University

MONDAY 16-MONDAY 30
ROME International electronic, atomic energy, television, radio and cinema exhibition. Atomic energy conference

SUNDAY 22-SATURDAY 28
ROME Electronics conference

TUESDAY 24-THURSDAY 26
LONDON The Chemical & Petroleum Engineering Exhibition. Symposium on The organization of chemical engineering projects. Both at Olympia

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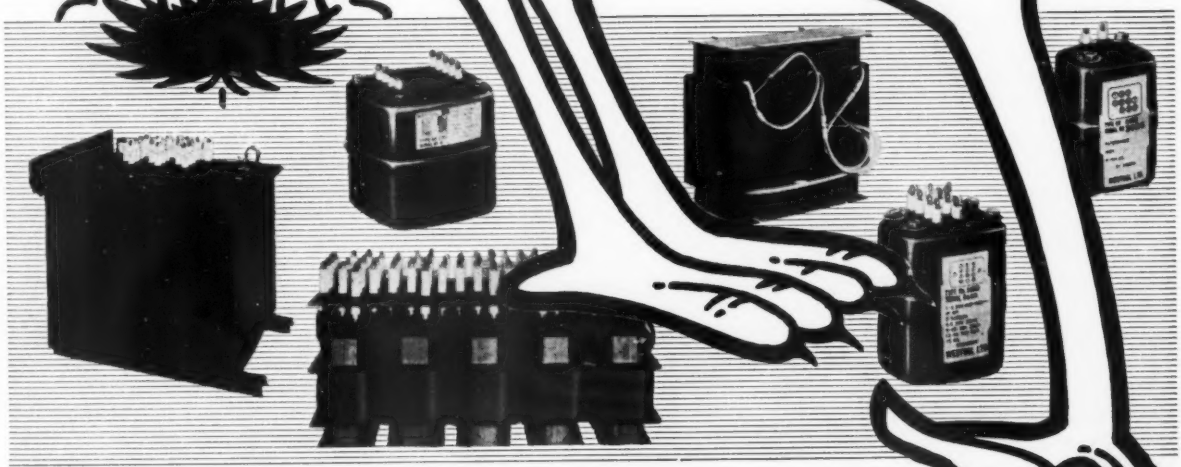

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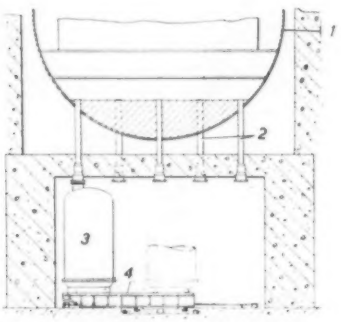
# NEW IDEAS
## nucleonic patents

### Charging machine

Hunterston power station, under construction by the GEC, contains several features not shared with similar plants, and one of these is the fuelling arrangements entirely from below the spherical pressure vessel. This patent is fairly wide in its scope but it includes this proposal. Briefly it covers the use of an auxiliary pressurized charging machine which is connected as required to a charge tube. The patent covers the use of separate vessels for charging and discharging but in the specific application similar to the one used at Hunterston there is only one.




789,022 FUELLING FROM THE BASEMENT
1 Reactor sphere
2 Charge tubes
3 Fuelling machine
4 Rails

The general arrangement can be seen from the diagram. The pressurized fuelling machine runs radially on rails which in turn rotate on a turntable about the vertical centreline of the reactor. Thus it can be moved to connect with any given charge tube.

789,022 Improvements in or relating to nuclear reactors *General Electric Co Ltd* (Inventors: W. M. Brown and K. J. Mitchell) Appn: June 10, 1955 Pubd: Jan 15, 1958

### Improved cooling

Unlike most of the recent spate of patents published by GEC, this idea is not incorporated in Hunterston. It is a device for improving the heat transfer from finned fuel elements by arranging the coolant flow to be transverse to the element. The coolant channel is in effect divided into two parts parallel to the elements, gas entering one part, passing over the fins and being led off through the other. It means that each part of the element is cooled by gas which has not been used for appreciable cooling in any other part of the element. Thus with the same total flow and inlet temperature of coolant a higher rate of heat transfer from elements in the central high-flux region of the core can be achieved. Another advantage is that heat is removed from the whole of the fin and not only the tips so that the elements can be run at a lower temperature for the same fin temperature. Also the inventors claim that the degree of turbulence required in the coolant is not so high as with straight through flow and a lower powered blower can be used.

790,688 Improvements in or relating to heat transfer arrangements *General Electric Company Ltd* (Inventor: D. A. Boyland) Appn: March 18, 1955 Pubd: Feb 12, 1958

### New approach to fpd

One of the disadvantages of detecting can failure by monitoring the coolant is that radioactive materials other than fission products are present in the coolant due to neutron irradiation. This patent, which applies to a liquid-cooled reactor, suggests a method of stripping the gaseous fission products from the coolant and transferring them by a non-radioactive carrier gas, such as helium, to a detecting chamber. The stripper may be of two kinds: either one which provides an interface between the coolant and the carrier gas, allowing the fission products to diffuse into it—for example a bubble chamber or a spray chamber—or one in which the fission products are removed from the coolant and then mixed with the carrier—for example a fractionating column. The type described is a spray tower in which a falling film of liquid presents a large surface area to the carrier gas.

793,905 Method of and apparatus for detecting gaseous fission products in effluent liquid. *Atomic Energy of Canada Ltd* Appn: August 5, 1955 Pubd: April 23, 1958

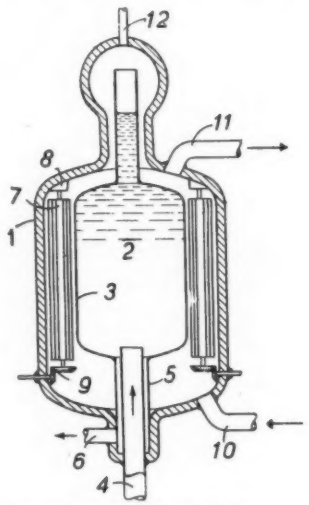
### Power from beta-emission

Although the application for this patent was made as long ago as 1945, it has only just been published. Its object is to use the beta rays emitted during fission —which comprise about 10 pct of the total energy released—to generate electricity. Wires or thin cylindrical rods of fuel are surrounded by cylindrical beta collectors of a suitable conductor with a low neutron-absorption cross-section. Insulation is obtained either by evacuating the space between the wire and cylinder or filling it with insulating material. The cylinders and wires are electrically interconnected to two line terminals, and beta particles collecting on the cylinder walls set up a potential difference with respect to the fuel. High-voltage, low-current power is derived from the line terminals, suitable for direct application to mass spectrographs or for uses where a Van de Graaff is usually employed.

791,941 Generation of electrical power *United Kingdom Atomic Energy Authority* Appn: July 3, 1945 (in the USA) Pubd: March 12, 1958

### Superheated steam from a reactor

This is a solution-type breeder reactor in which blanket heat is used to superheat steam produced by normal heat exchange from the core. The aqueous fuel solution—slightly enriched natural U, U-233 or plutonium in light or heavy water—is circulated through the core chamber 2. The blanket through which steam is passed consists of a series of concentric cylindrical plates, rotatable about the vertical axis to ensure equal




793,919 SOLUTION-TYPE BREEDER
1 Pressure vessel
2 Core chamber
3 Baffle
4 Fuel inlet pipe
5 Fuel outlet duct
6 Fuel outlet pipe
7 Blanket
8 Bearings
9 Gear drive
10 Steam inlet
11 Steam outlet
12 To pressurizer

exposure of all their surface to the neutron flux. The blanket fuel may be U-238 or thorium and may include small percentages of fissionable materials. A steam pressurizer, 12, is connected into the extension of the pressure vessel at the top. This extension and a similar one on the core enable the pressure to be equalized in the core and blanket chambers so that the core chamber baffle, 3, can be of minimum thickness. A modification of the design is also described in which the fuel consists of discrete elements instead of solution.

793,919 Method and apparatus for generating and superheating steam from nuclear energy *Babcock & Wilcox (USA)* Appn: November 30, 1955 Pubd: April 23, 1958

*These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, W.C.2. 3/6 a copy (including postage, inland and abroad)*

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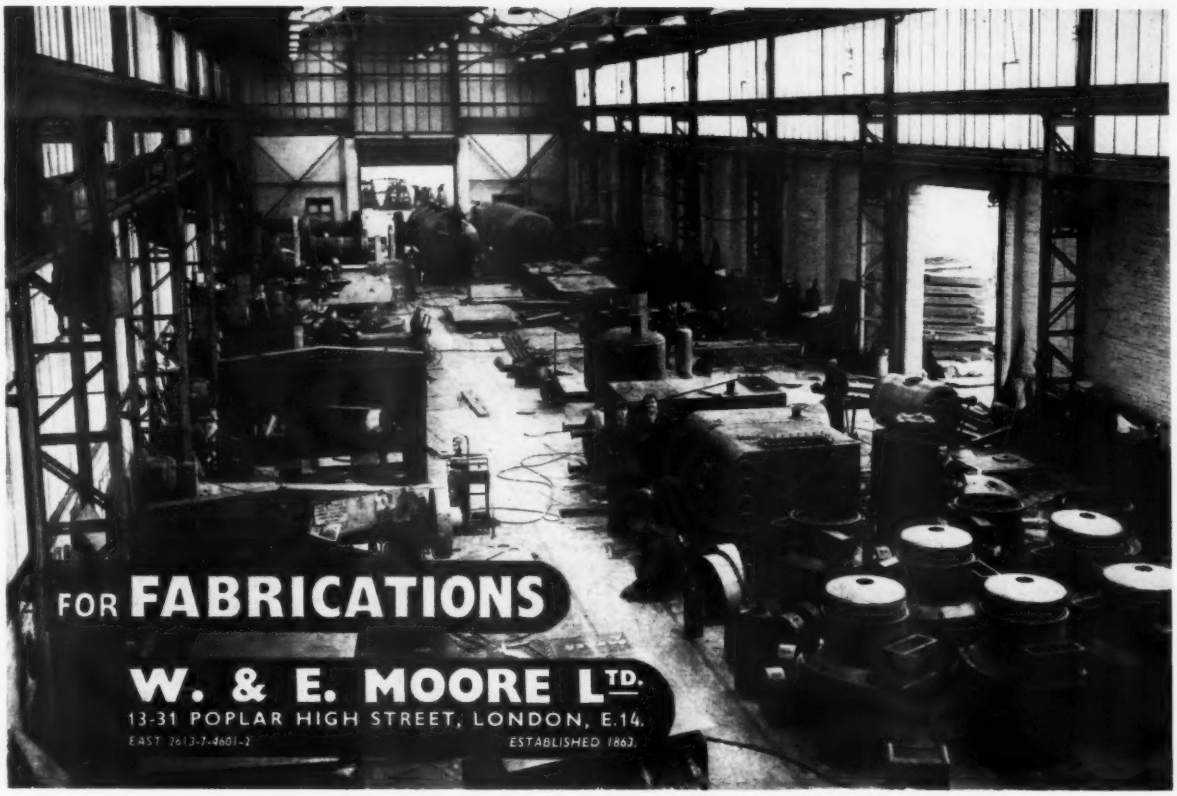


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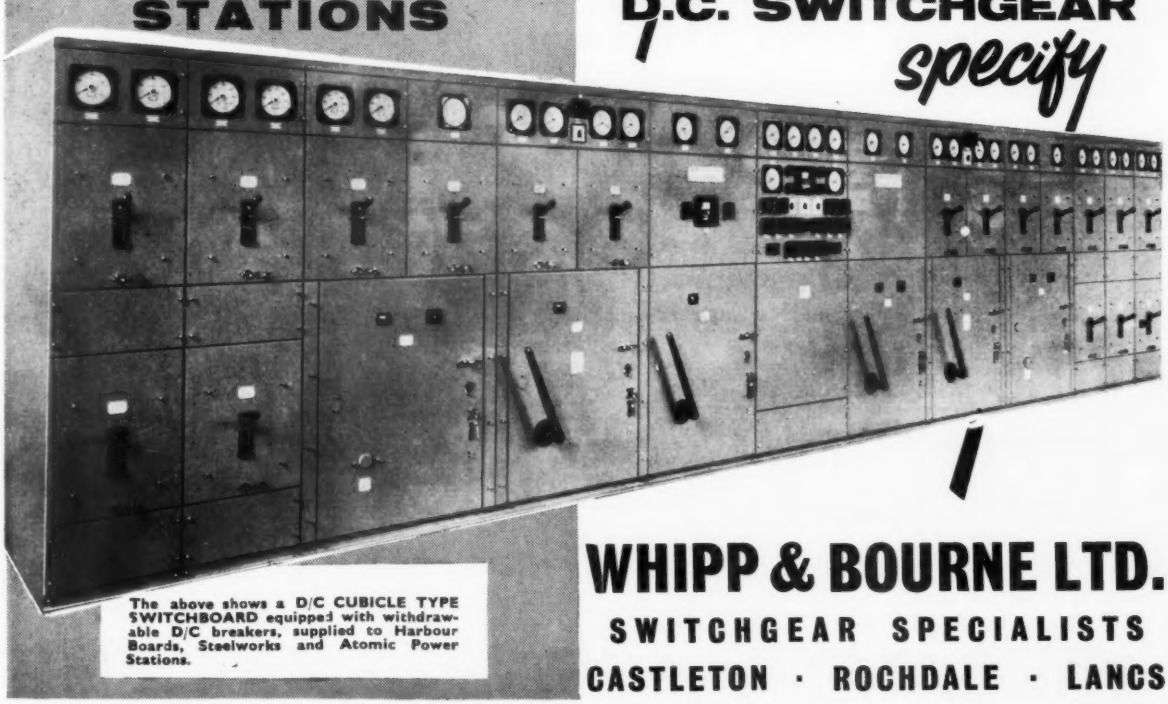

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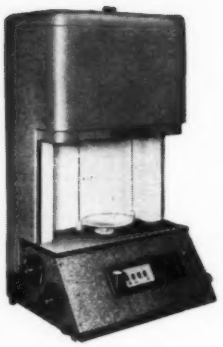

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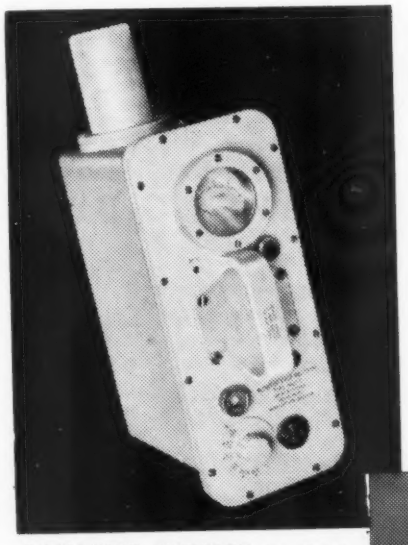

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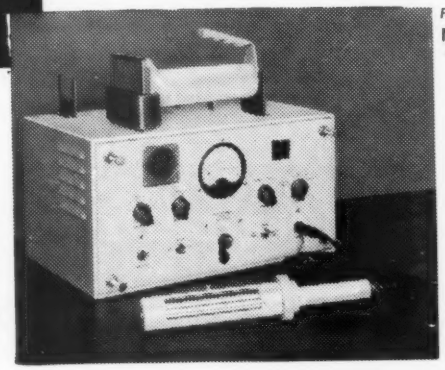

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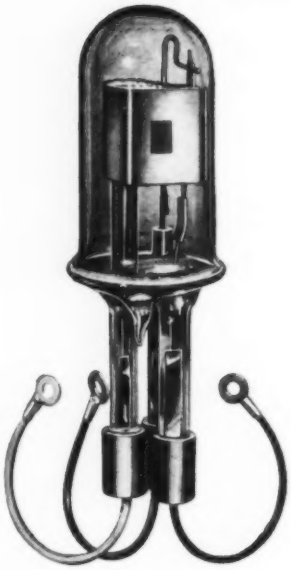

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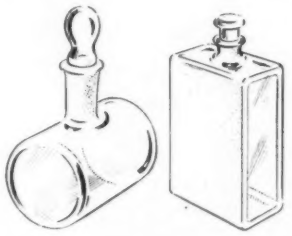

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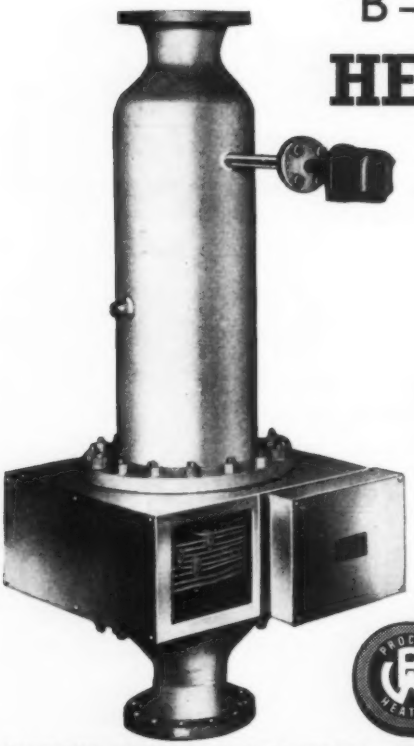

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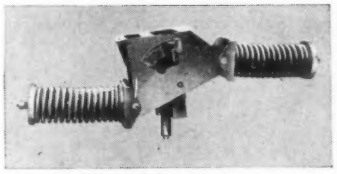

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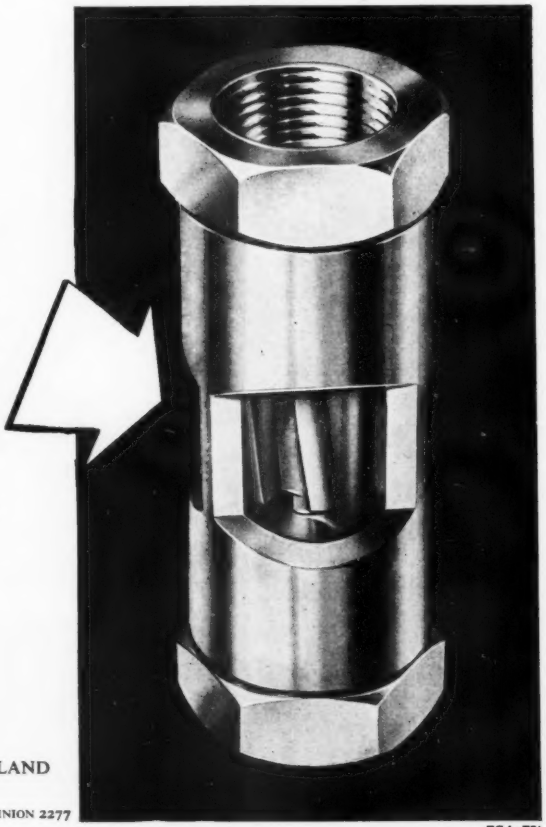

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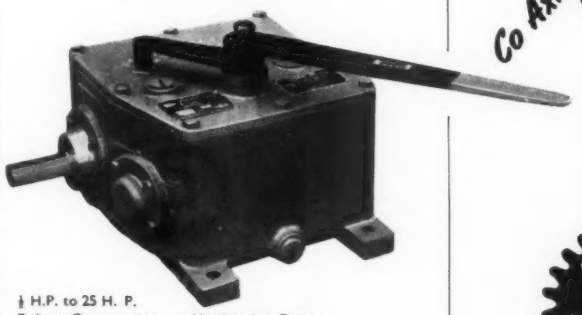

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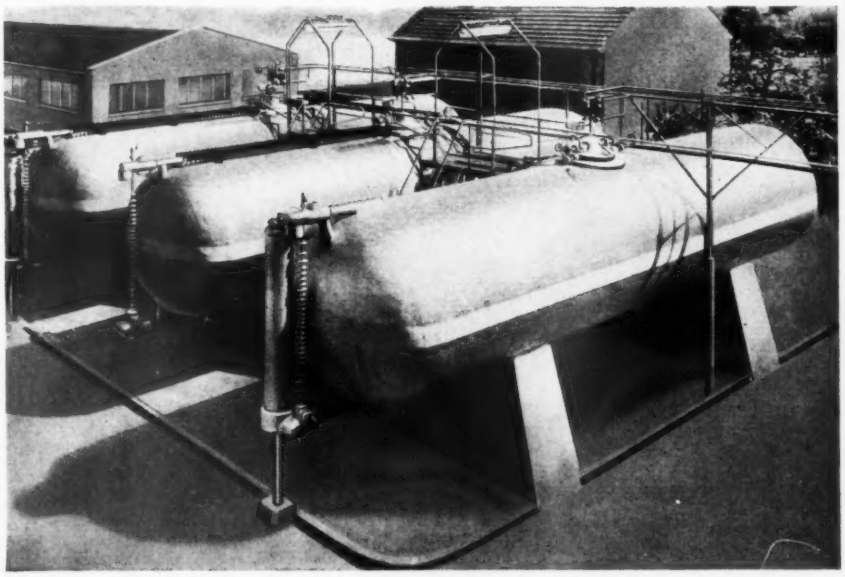

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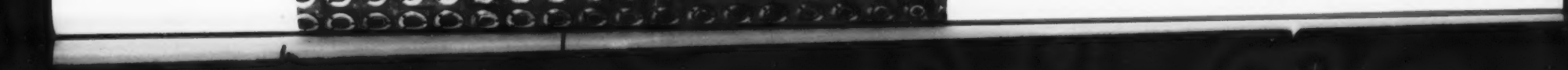

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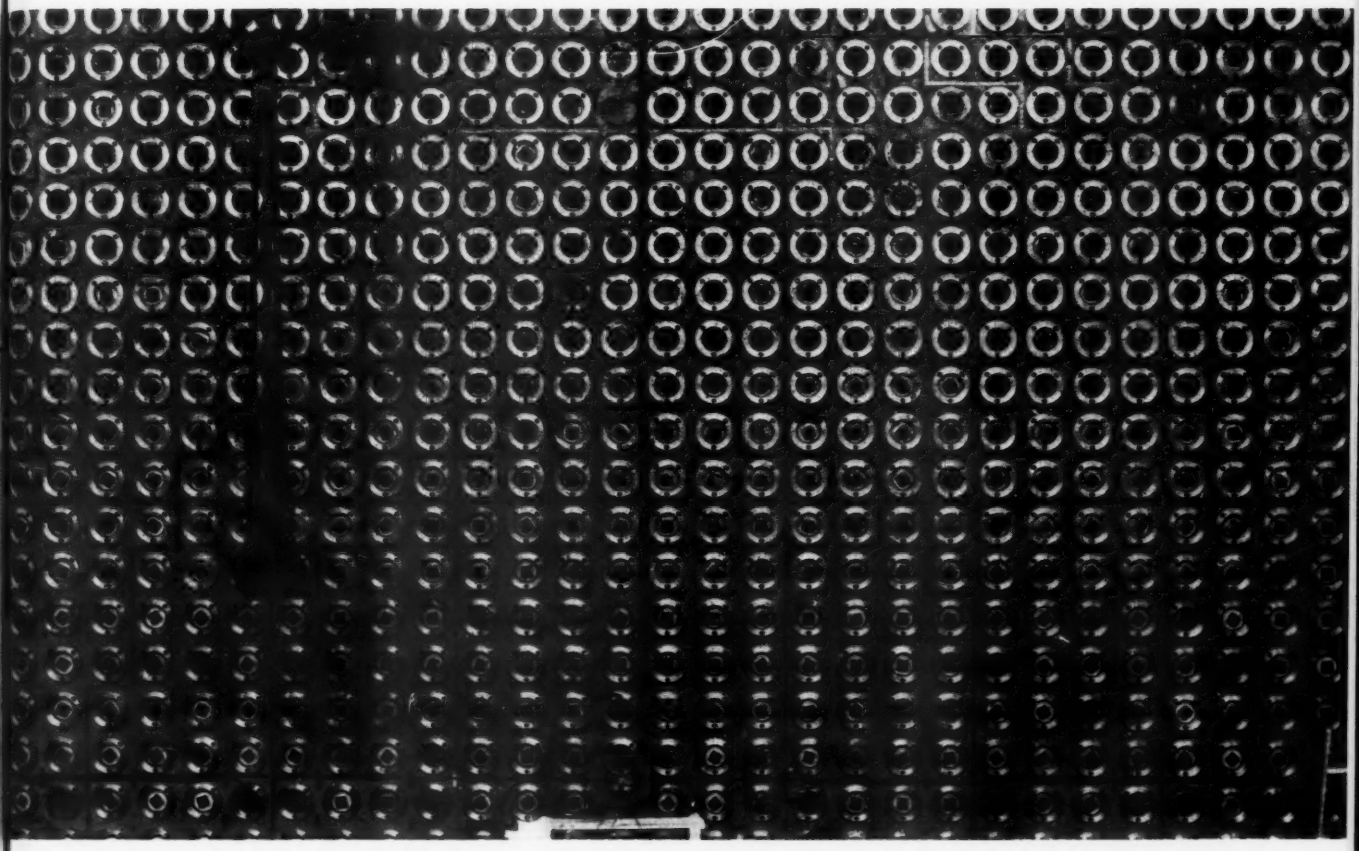

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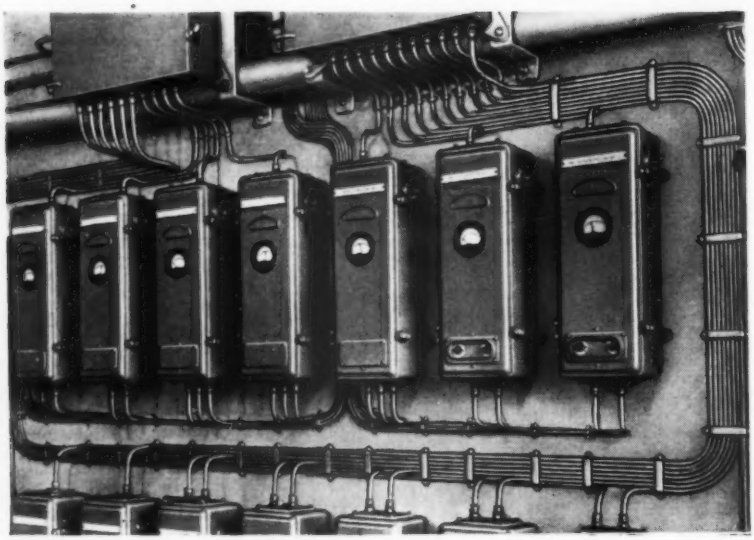

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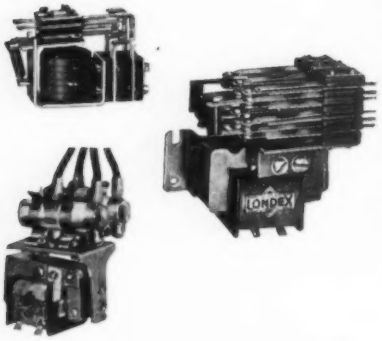

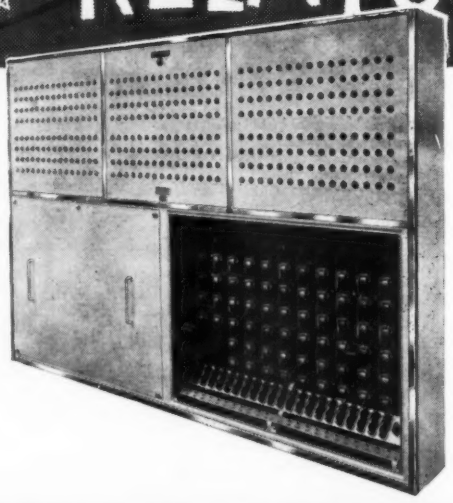

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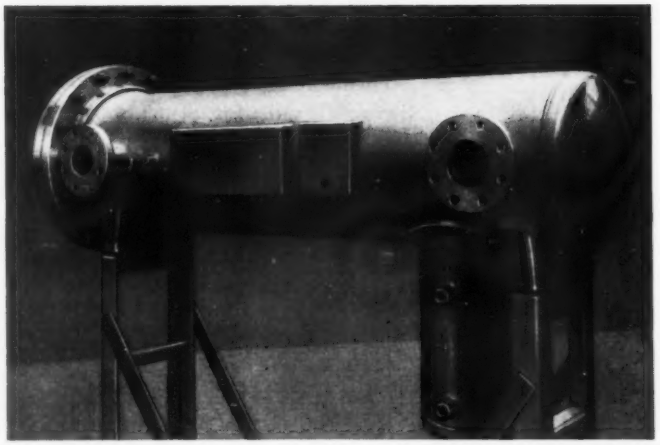

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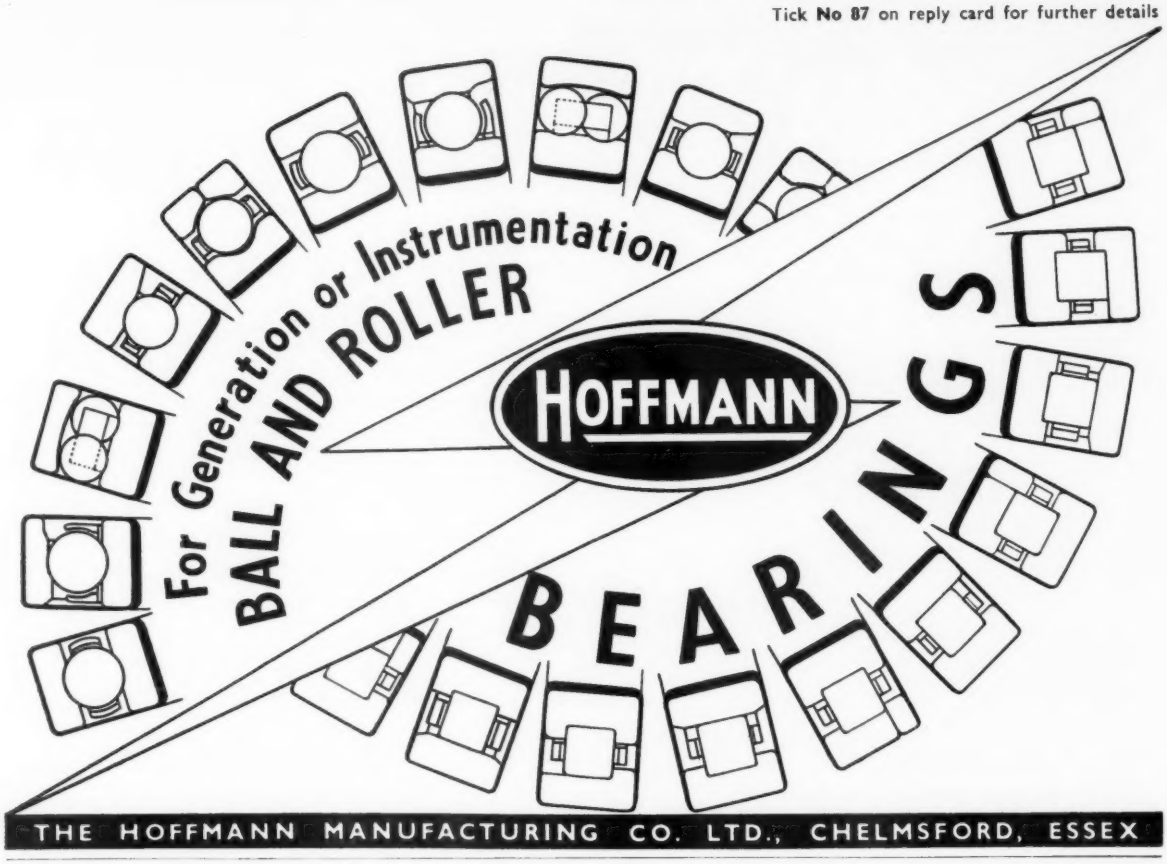


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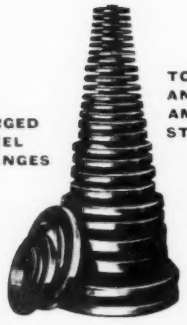

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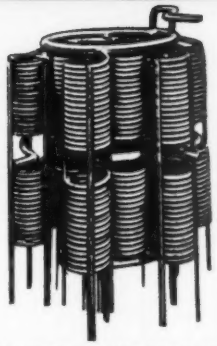

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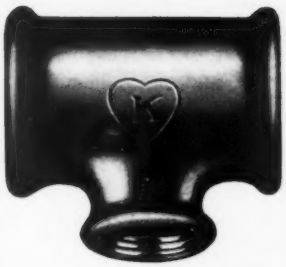

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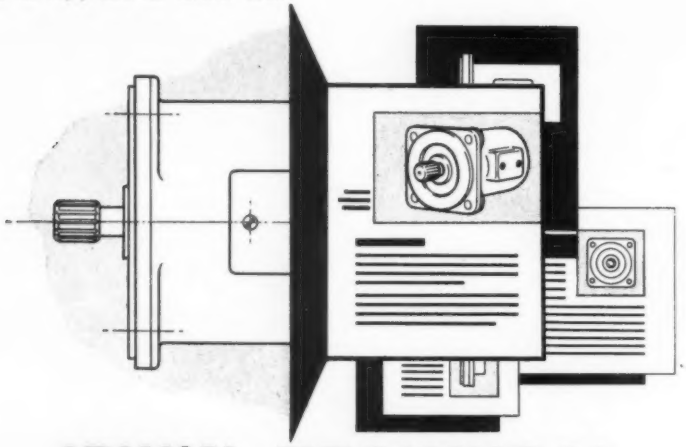

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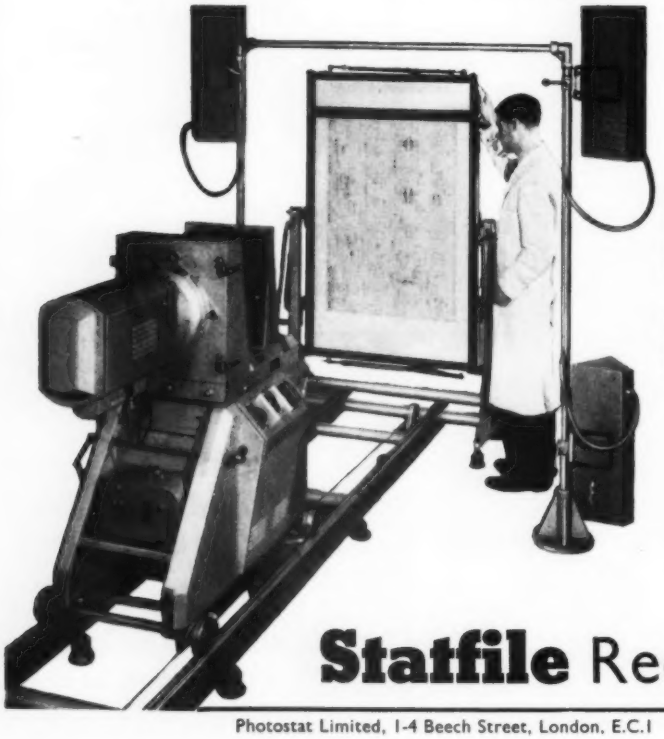

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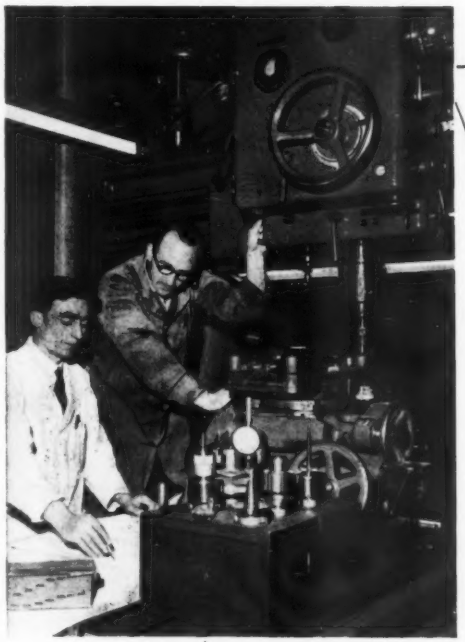

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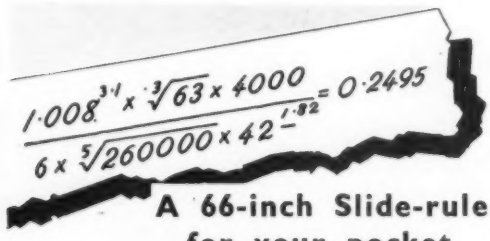

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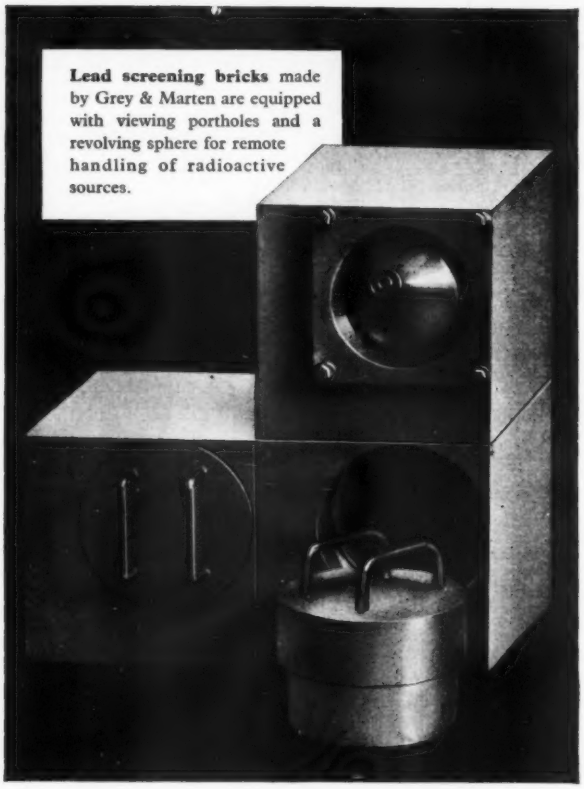

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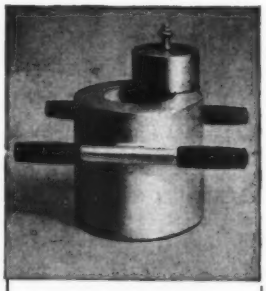

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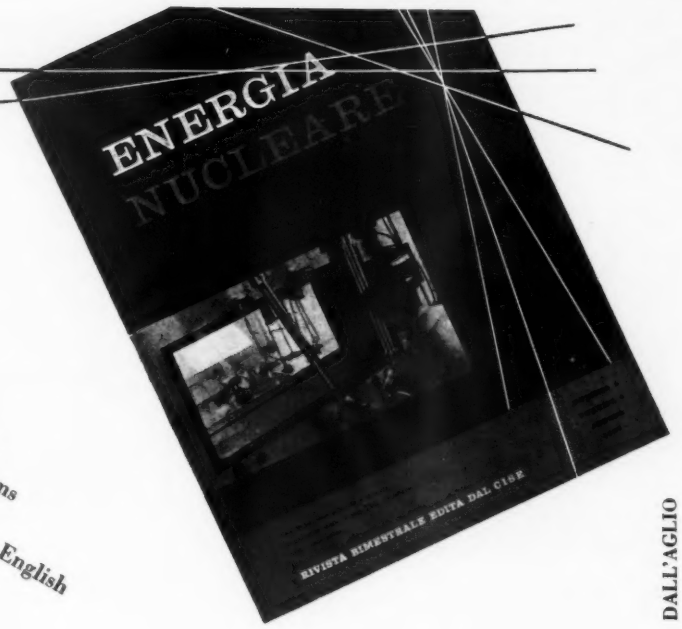


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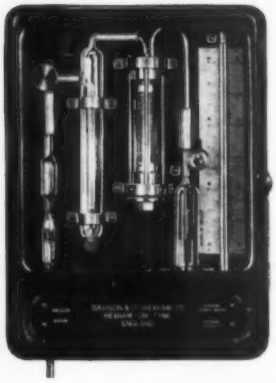

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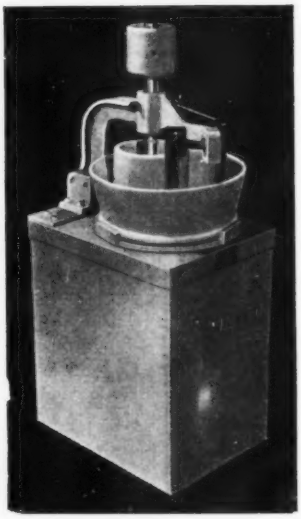

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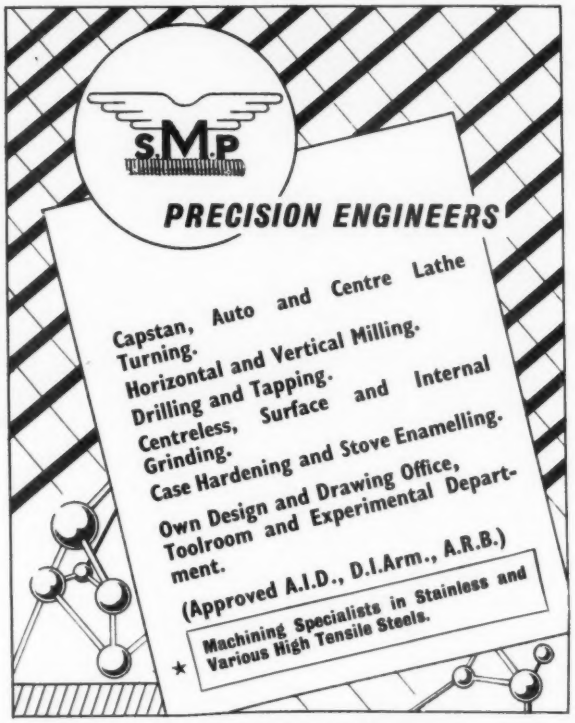
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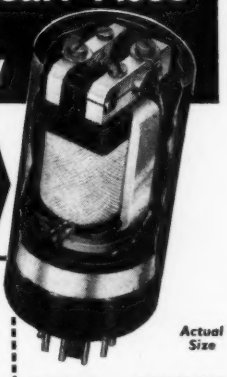


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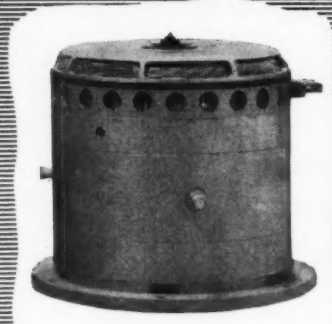

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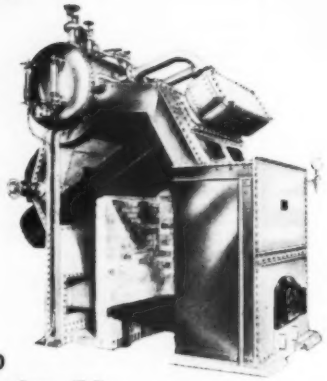

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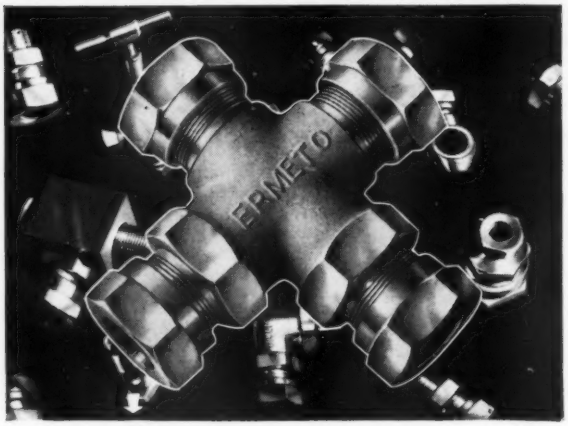


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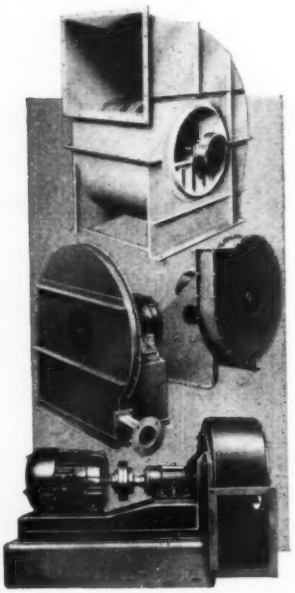

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| REMITTANCES | Cheques and postal orders should be sent to Rowse Muir Publications Ltd with the order for the advertisement |
| PRESS DAY | Advertisements must be received not later than June 17 for the July issue |
| TERMS | All advertisements are strictly net and must be prepaid |
| HEAD OFFICE | All advertisements should be addressed "Classified Advertising," NUCLEAR POWER, 3 Percy Street, London, W1 |
| BOX OFFICE REPLIES | NUCLEAR POWER, 3 Percy Street, London, W1 |

**NUCLEAR POWER STATION CONSTRUCTION**
**DEPUTY RESIDENT ENGINEER**

A Deputy Resident Engineer is required by one of the industrial consortia engaged on the construction of a nuclear power station in the U.K. for the Central Electricity Generating Board.

Applicants should have had sound and progressive experience in the administration, co-ordination and supervision of large-scale operations involving a number of major contractors, each with their own construction organisations and responsibilities. The position requires a man possessing the necessary personal qualities to establish authority in these circumstances.

Preference will be given to candidates who hold an Honours Degree in Electrical or Mechanical Engineering, or are corporate members of one or more of the major professional Institutions.

Experience in the design and construction of conventional generating stations is desirable, though experience in the erection of large chemical, oil refinery or similar large industrial plants may also be acceptable.

The candidate selected should be prepared to work on nuclear power station sites in this country or abroad.

Please write stating age, qualifications and experience to Box NP 4016 LPE, Romano House, 399/401, Strand, London, W.C.2.

## SITUATIONS VACANT

ACTIVE MANUFACTURERS AGENTS required to represent well known manufacturer of specialized equipment for the nuclear, electronic and electro/mechanical fields. Generous commission. Write with details of past activities and other lines covered to Box NP992, LPE, Romano House, 399/401 Strand, London W.C.2.

**GROUP EDITOR**

A Group Editor is required by a large technical publishing house for directing the editorial policy and development of a number of technical publications. This is a major executive appointment and calls for an experienced technical journalist with a scientific background who is already in a senior editorial post. Apart from being an authority on the preparation and editing of technical articles and data, he must have up-to-date knowledge of the requirements of engineers and technicians concerned with the engineering, electronic, chemical and plastics industries. For this position a high salary will be paid, but only those possessing the right qualifications will be considered for interview. All applications will be treated as strictly confidential. This vacancy is known to the present editorial staff. Box No. 42

REPRESENTATIVE required by manufacturer of special equipment for electro/mechanical, electronic and nuclear field. Appreciation of assembly and handling problems an asset. Salary according to qualifications. Generous commission. Write Box NP993, LPE, Romano House, 399/401 Strand, London W.C.2.

**THE UNIVERSITY OF MANCHESTER**

Applications are invited for two posts of LECTURER IN ENGINEERING (MECHANICAL). For one post a prime interest in thermodynamics applied to heat engines is required; for the other, interests in applied thermodynamics, heat transfer mechanisms or machine design. University regulations permit teaching staff to read for the degrees of MSc and PhD. The salary scale is £900 to £1,650 per annum. Membership of the FSSU and Children's Allowance Scheme. Initial salary according to qualifications and experience. Applications should be received within 10 days of the appearance of this advertisement by the Registrar, the University, Manchester 13, from whom further particulars and forms of application may be obtained. Applications by airmail (no forms) will be considered from overseas candidates.

**UKAEA**
**Harwell Reactor School**
**Control and Instrumentation of Reactors Course**

A course on 'The Control and Instrumentation of Reactors' is to be held at the Harwell Reactor School from 6th to 11th October, 1958, inclusive.

The fee for the course will be 25 guineas exclusive of accommodation.

Application forms and further details can be had from

The Principal,
Reactor School,
Atomic Energy Research Establishment,
Harwell, Berkshire

**SENIOR LABORATORY TECHNICIAN**

A senior laboratory technician is required to assist in the development and engineering for production of radiation detectors for the nuclear engineering industry. Experience in this field would be an advantage but is not essential. A knowledge of light engineering and general physics laboratory practice including high vacuum techniques is desirable. The position involves the development of new designs to meet a wide range of detector problems presented by the Company's rapidly expanding programme. Pleasant working conditions and an attractive salary are offered to the right man. Applications should be made in writing to The Personnel Department, Plessey Nucleonics Limited, Weedon Road, Northampton.

**BABCOCK & WILCOX LIMITED**
**ATOMIC ENERGY DEPARTMENT**

require Engineers, Mathematicians or Physicists with knowledge of nuclear reactor systems and experience of reactor performance, fuel cycle, control, shielding and health physics problems.

Junior positions are also available in this expanding organisation.

Apply, giving full particulars of education and experience to:—
The Assistant Secretary, 209 Euston Road, LONDON N.W.1.

## SUB-CONTRACTING

ELECTROPOLISHING—specialists in electro-polishing of all sizes of stainless steel fabrications at greatly reduced cost compared with mechanical polishing. Fully approved for Atomic Energy work. Electropol Processing Ltd., Trading Estate, Farnham, Surrey.

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RICHARD DENDY & ASSOCIATES of 4, 5 & 6 Seaton Place, Hampstead Road, London N.W.1. EUSton 7617 are makers of fine MODELS and invite your enquiries.

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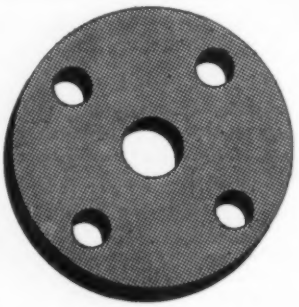

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NUCLEAR POWER is published by Rowse Muir Publications Ltd, 3 Percy Street, London, W1, England, and printed by The Haycock Press, Ltd., S.E.5

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*for*

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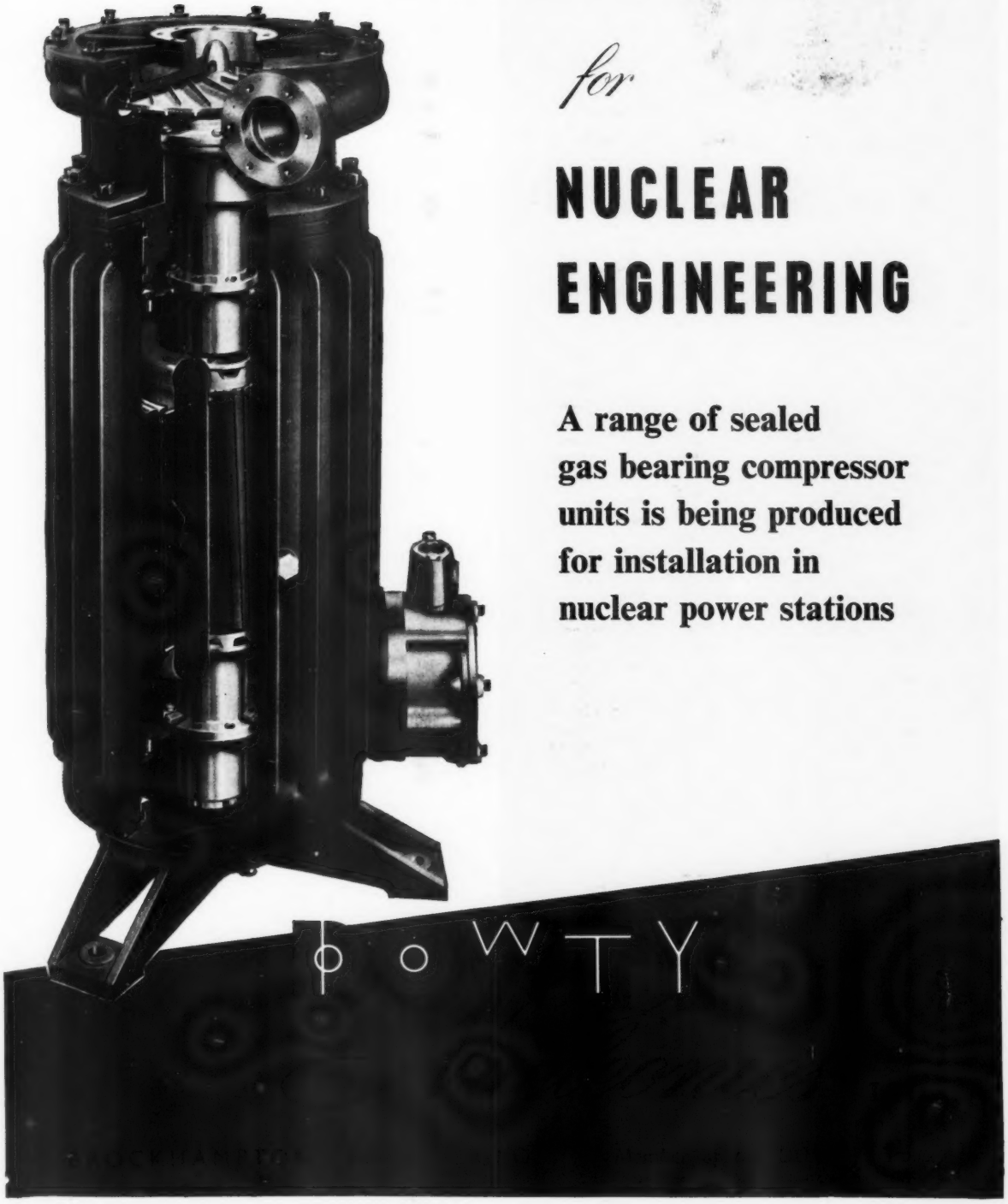

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The journal of British nuclear engineering

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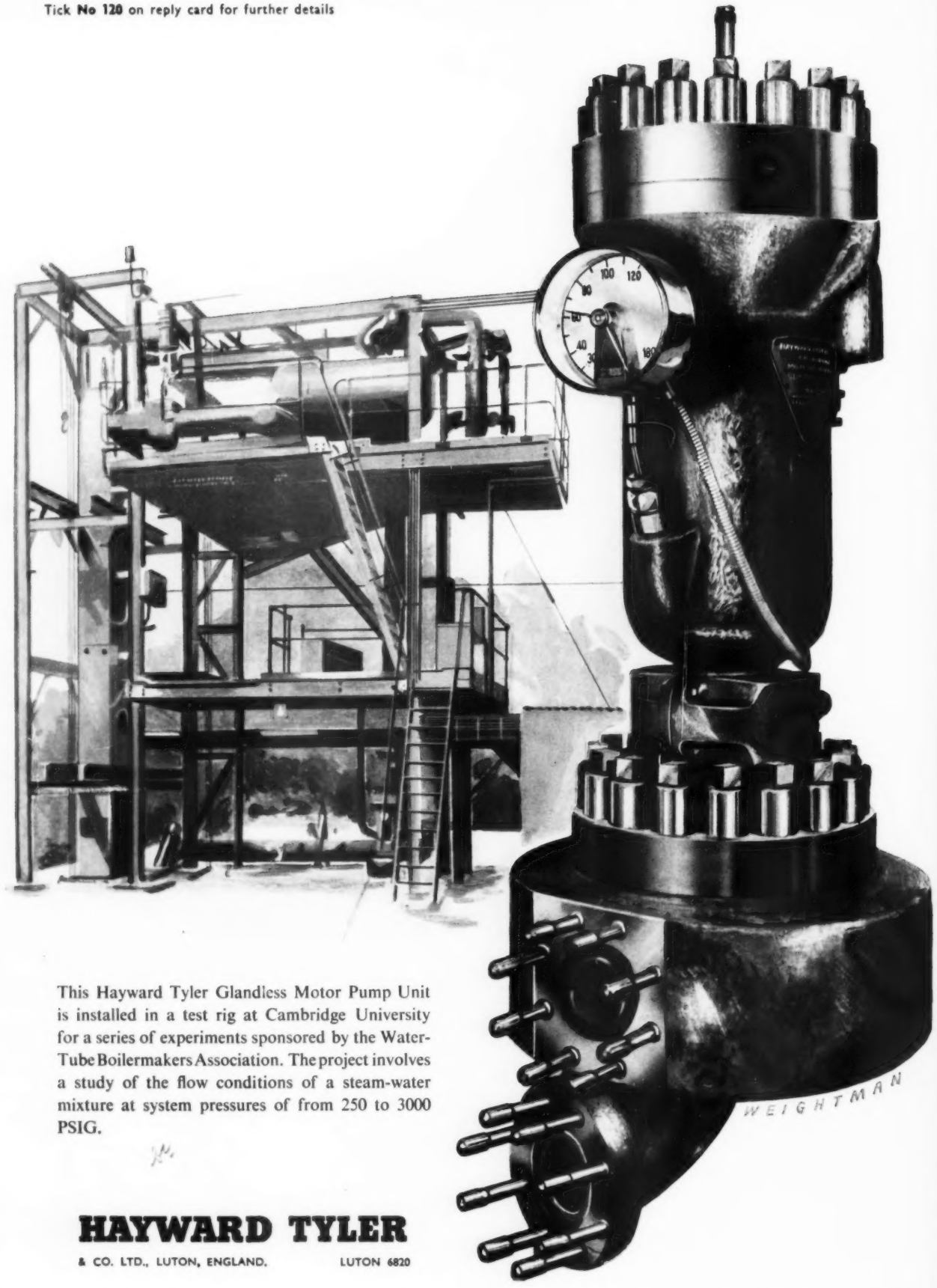


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